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THESIS

MODERNIZATION OF THE MULTIPLE LAUNCH ROCKET SYSTEM EMBEDDED SYSTEM SOFTWARE

by

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MODERNIZATION OF THE MULTIPLE LAUNCH ROCKET SYSTEM EMBEDDED SYSTEM SOFTWARE

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ABSTRACT

Weapon systems in the Department of Defense (DoD) are becoming increasingly reliant on embedded software. As the size and level of complexity of these software development efforts have increased, the management of these programs has become more challenging. Additionally, as the Army strives to digitize the future battlefield, the demand for software will only increase. This thesis reviews the software development efforts associated with modernizing the Army's Multiple Launch Rocket System (MLRS). The thesis begins by presenting a background discussion of the Army's Fire Direction Data Manager (FDDM) development. After the FDDM background discussion, a case study of the troubled FDDM software development effort is presented. The FDDM case study follows the general format presented in the May 1992 General Accounting Office report on the FDDM software development difficulties. Following the FDDM review, the current MLRS software development effort, the Improved Fire Control System (IFCS) is presented. Next, the FDDM case study is reviewed to determine the software development lessons learned. Using the FDDM software lessons learned, the IFCS program is analyzed to determine the software risks, and to review the risk mitigation strategies of that program. The objective of the thesis is to provide insight into the use of modern software management methods in reducing software development program risk.

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I. INTRODUCTION

The Multiple Launch Rocket System (MLRS) was originally designed as a self-propelled launcher capable of firing up to 12 dual purpose rockets in a field artillery mission role. Beginning in 1985 the Army decided to increase the utility of the MLRS by firing missiles as well as rockets. The Army Tactical Missile System (ATACMS), which was then under development, was intended to be the first missile to use the MLRS launcher. However, the existing MLRS fire direction system could not provide the additional communications and data processing capabilities that the missile required. The Army decided to provide those capabilities through a new system already under development, the Advanced Field Artillery Tactical Data System (AFATDS), scheduled to be ready when ATACMS was deployed in 1990.

The AFATDS, however, would not be completed in time to support the ATACMS operational tests scheduled to begin in 1989. To meet the ATACMS operational test requirements, the Army contracted in March 1986 for development of hardware and software to provide a test device that would mimic the AFATDS-ATACMS interface. This test device was designated as the Fire Direction Data Manager (FDDM).
[Ref. 1, p. 1-1]

Development of the FDDM was the responsibility of the MLRS Project Manager (PM). Within the MLRS project office, a product management office for the M270 Family of Munitions Command, Control, Communications, and Intelligence (MFOM C^3I) was established with the responsibility of coordinating efforts between the MLRS PM (located at the Army Missile Command) and the AFATDS PM (located at the Army Communications and Electronics Command).

In 1987, the Army delayed the AFATDS deployment date until 1993. This meant that AFATDS would not be ready to support the ATACMS fielding in 1990. At the direction of the Army Deputy Chief of Staff for Operations, the MLRS PM was directed to field a limited number of FDDM systems to support the scheduled ATACMS deployment. This changed the mission of the FDDM from that of a test device to a fieldable system. The requirements changes generated by this decision would significantly effect the FDDM development program.

In 1992, the General Accounting Office (GAO) reported that the FDDM software development program was behind schedule, over cost, and would not meet operational requirements. According to the GAO, the primary causes of these development problems were a failure to adequately define initial requirements and a lack of enforcement of the Department of Defense (DoD) software development standard. [Ref. 2, p. 1]

By July 1994, however, the Army PM had overcome these problems and successfully fielded the FDDM to Army field artillery units. Currently, the MLRS PM is undertaking a new development effort to modernize the Fire Control System of the MLRS launcher. The Improved Fire Control System (IFCS) is similar to the FDDM development effort in many ways and may present similar software development challenges.

A. PRIMARY AND SUPPORTING RESEARCH QUESTIONS

The objective of this thesis is to establish the lessons learned from the FDDM software development effort. With these lessons learned, an analysis of the IFCS development strategy, identifying software risk areas and proposed methods to reduce or control these software risks in the IFCS development program, will be made.

1. Primary Research Question

The primary research questions for this thesis are, how was the software for the FDDM developed, and what lessons learned from that effort can be applied to the IFCS?

2. Supporting Research Questions

The supporting research questions for this thesis are as follows:

- What difficulties were encountered in the FDDM development effort, and of these, were they foreseen as risk areas by the project manager?

- What effects did the choice of Ada, as a programming language, have on the complexity and level of difficulty in the software development effort for the FDDM?
- In what ways did requirement changes affect the software development of the FDDM?
- Was the primary contractor for the FDDM software development effort sufficiently qualified (mature) for that program?
- What type of contract was used for the development of the FDDM software, and what specific military standards, specifications, and metrics were called for in that contract? Was this the best type of contract for this design effort?
- What type of contract is being used to develop the IFCS software, and what specific military standards, specifications, and metrics will be called for in that document? Are there any shortcomings in this contract?
- What other software development efforts have been considered, or used as models, for the software engineering effort for the IFCS?
- Under DoD Standard 2167A, what tailoring has been done, and how is the contractor implementing these modifications?

B. RELEVANCE AND APPLICABILITY OF THIS THESIS

The modern battlefield has become digitized as an array of computers and embedded computer subsystems significantly influence the scale and pace of warfare. The United States (US) has maintained a commanding lead in the development of automated weapon systems. Increasingly these systems are being modernized in the face of changing threats, doctrine, enemy weapon systems, and technology. To keep pace with these trends, the Department of Defense (DoD) must design weapon systems *for* change - rather than *to* change. That is, our weapon systems today must be designed for flexibility and growth, that they might meet future threats, not only the threats of today. One design method that has provided this level of flexibility is the reliance on software to perform missions that previously only hardware systems could perform. By automating many hardware design features, software changes can more rapidly respond to changes in the system operational environment.

What does automation give us? It gives us the ability to design weapons that push physical limitations to extremes; the ability to make better decisions faster than potential adversaries; and the ability to build weapon systems that *multiply* the combat effectiveness of our soldiers, sailors, and airmen. Automation also gives us the ability to wage a new dimension in warfare: "information war" - or literally, a war of command, control, communications, and intelligence (C^3I). Desert Storm was the first application of this new style of warfare, as illustrated by the following statement:

> Over the Gulf flew two of the most powerful information weapons of all - AWACS and JSTARS. Boeing 707 aircraft crammed with computers, communications gear, radar, and sensors, the AWACS (Airborne Warning and Control System) scanned skies 360 degrees in all directions to detect enemy aircraft or missiles and sent targeting data to interceptors and ground units.. [Ref. 3, p. 70]

1. Relevance of This Thesis Topic

In the context of this thesis, the term "digital weapon system" refers to those weapon systems that rely whole or in part upon the use of digital computer technology for successful mission operation and function. More specifically, this thesis is concerned with the development of the embedded software that operates the mission critical computer resources that have been designed into modern digital weapon systems.

Weapon systems of today are increasingly more reliant on embedded computer systems software. As the trend toward automation continues, weapon system complexity is driven by the increasing size and complexity of software for the system. More frequently, we are seeing the tendency of engineers and designers to ask software to perform that which hardware cannot perform (or cannot perform at a reasonable cost). As the relative cost of computer hardware has fallen (in terms of speed and memory capacities), weapons designers are taking advantage of this opportunity. Figure 1 shows the growth in size of aircraft computer memory requirements since 1965. This trend is analogous to the growth in software size and complexity over the same period. [Ref. 4, p. 2-2]

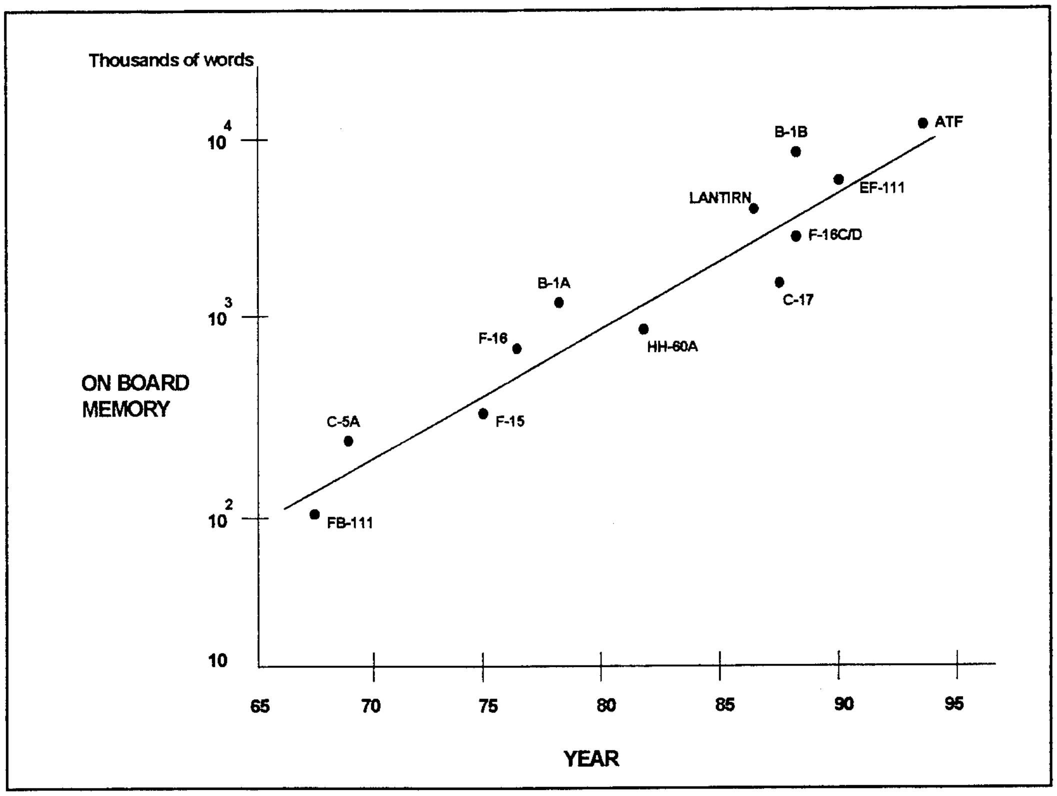


Figure 1 - Growth of Aircraft Systems Software [Ref. 4, p. 2-2]

As an example of the growth in the use of embedded computers and software, consider the case of the B-2 bomber. The B-2 derives much of its stealth characteristic from its extremely small physical cross-sectional area. To provide the aerodynamic lift necessary to carry large payloads, yet retain this small cross-section, the aircraft was designed as a "flying wing" - that is, it has no rudder control surfaces. The result of this design is an aircraft that is inherently aerodynamically unstable. The only way to control the aircraft is to make constant control surface corrections that respond (in real time) to humanly undetectable changes in surface air pressures. This is accomplished by "pushing off" much of the aircraft's control system function into digital automation. This "fly by wire" design enables the human pilot to direct the aircraft's movement at the macro level while the "real" flying is done by the on-board system of sensors, computers, and software.

As designers have relied more heavily on computers in the design and development of new systems, embedded software has played an increasingly important role in the overall system design. If we consider a system's total design effort, we could divide the total effort between the two general design areas of hardware and software. The relative influence of either hardware or software could be defined as the percent of total engineering and design hours for the system design. As an example, consider how designers have replaced many control switches and knobs with "soft" keys on multifunction displays (MFDs). In this way (and others) designers are replacing hardware designs with software designs. As Figure 2 shows, today the relative influence played by software has displaced hardware. Where hardware design predominated earlier design efforts, today software consumes a larger portion of the total design. According to the *Mission Critical Computer Resources Management Guide*:

> It is very clear that in 1950 software had no influence on weapon systems design. This is because these systems contained no digital hardware. By 1980, however, the relative influence of software on system design averaged about 50 percent with some systems being influenced by as much as 70 percent or as little as 30 percent. This means that software considerations affected overall system design and development about 50 percent of the time. System engineers could no longer make hardware design decisions without considering the software implications. As can be seen, the trend seems to be for an increasing role for software.
> [Ref. 4, p. 2-3]

As mentioned previously, modern weapon systems are being employed as part of "information warfare". On-board computer systems track and prioritize targets, assign targets to other weapon systems, manage communications traffic, and continuously inform the operator (and external users) of threats, targets, and status. The computers embedded in modern weapon systems are linked with external systems to provide operators the capabilities of other perspectives of the battlefield. Many of our weapon systems today are more a part of a distributed C^3I processing network than a discreet weapon.

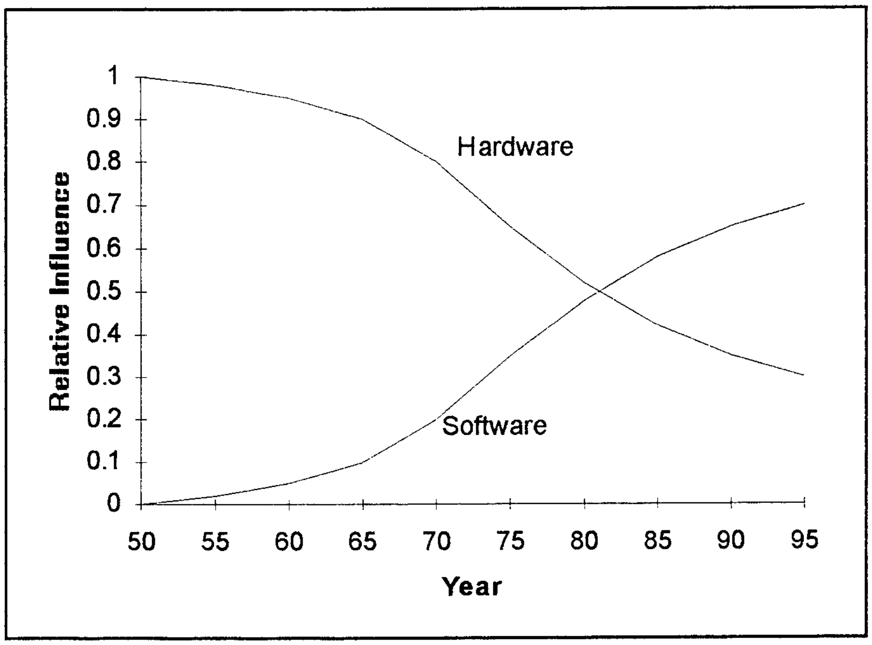


Figure 2 - Software Impact on System Design/Development [Ref 2, p. 2-3]

This is the essence of "information warfare" - linking systems together intelligently by sharing information resources to multiply the combined effects across the battlefield. The 1995 Army Posture Statement established the requirements for this "digitization of the battlefield" as one of the Army's key modernization initiatives:

> The creation of the digitized battlefield is crucial to the Army's efforts to maintain a small, modern force capable of decisive victory. Digital data networks will allow rapid transmission of critical battle information to soldiers throughout the battlefield. This technology allows an Army commander to visualize the battle more clearly and to control its pace by closely linking tanks, fighting vehicles, fire support, command centers, higher headquarters, helicopters, and unmanned aerial vehicles. [Ref. 5, p. 87]

As the Army modernizes its weapons platforms through digitization, review of case studies (such as the FDDM) will play an increasingly important role in future software management decisions. In the next section, a discussion of how this thesis may be applied within the DoD to improve the management of embedded software acquisition management will be presented.

2. Applications of This Thesis

Anecdotal evidence suggests that software acquisition management within the DoD is an area of increasing concern. GAO reports have cited numerous instances of cost overruns, schedule slippages, and performance shortfalls in major DoD weapon system development programs attributable to software. Programs including the Air Force C-17 cargo plane, the Army FDDM, and the Navy BSY-2 Seawolf combat system indicate that the DoD must improve how software systems are developed and managed. Compounding these management challenges, and given the trend of the past 20 years, the DoD will likely acquire more software in the future than it has in the past.

a. General Applications

At the same time that weapon systems increase their reliance on complex software systems, the available resources to produce software are becoming scarce. According to James Kitfield, a senior editor for *Military Forum*, the DoD is facing stiff competition from the commercial markets for software developers as the following statement illustrates:

> Any attempts by DoD to come to terms with its own software woes will play out against that backdrop of runaway demand and a profound shortage of software programmers. [Ref. 6, p. 28]

To deal with the simultaneous challenges of increased requirements for software and a shortage of available producers, Kitfield believes that DoD software acquisition officials must do two things. First, the DoD must better understand software acquisition; and second, acquisition managers must improve the methods used to control these development programs. One method that may be used to improve our understanding of the software acquisition process is to review programs that encountered serious software development difficulties.

In this thesis, the software development effort of the FDDM is reviewed. In better understanding the lessons learned from this program, DoD acquisition officials may improve the management of software development in future weapon systems.

b. Specific Applications

The MLRS PM is currently modernizing the fire control system for the MLRS launcher. The Improved Fire Control System (IFCS) development effort will upgrade the capabilities of the current launcher through a substantially more software-intensive, modular design. Because of the inherent modularity and flexibility of the IFCS design, the MLRS PM expects to improve how the MLRS launcher accommodates future missile and rocket systems. [Ref. 7]

The IFCS completed preliminary design review (PDR) in the second quarter of fiscal year 1994 and is currently undergoing detailed system design. This thesis will be available to the MLRS PM prior to the IFCS critical design review (CDR) scheduled for the fourth quarter of fiscal year 1995. The conclusions and recommendations of this thesis may provide assistance to the PM in the analysis of his software development strategy prior to this review.

In this section, I have discussed the relevance and applicability of this thesis to the DoD. As the DoD is increasingly dependent on software in future weapon systems, and as the commercial demand for programmers creates a shortage of available resources, acquisition officials must improve the software development process to capitalize on those resources available.

C. SCOPE OF THE THESIS

This thesis describes how the application of modern software development techniques in DoD embedded software systems can deliver more flexible and efficient products to the military user. This thesis presents a case study of the FDDM software development effort highlighting the numerous lessons learned by the MLRS project management office. Following this is a discussion of the current efforts underway to modernize the MLRS fire control system emphasizing the modern software management techniques being used to mitigate the technical risks in that system.

This thesis will explore how embedded software for the FDDM was developed, and how lessons learned from this, and similar efforts have been used to improve the design of the IFCS. Specifically, this study will provide an in-depth review of the management, software engineering (to include implications for the use of Ada), and contractual issues encountered in developing the FDDM software. While the history of the embedded software development process will be discussed generally, an in-depth case study and analysis will be presented on the development of the MLRS M270 Family of Munitions, Command, Control, Communications, and Intelligence (MFOM C^3I) and the IFCS software development efforts. This analysis should enable a generalization of those findings for application in future software development efforts. As such, the MLRS MFOM C^3I (FDDM) case study will be used as a vehicle to record lessons learned for the IFCS, and for similar software development efforts in the DoD.

The following section defines the research limitations to this thesis and describes the references and supporting documentation intended to be used.

1. Research Limitations

This thesis provides a review of the software development effort for the FDDM and records the lessons learned from the program. Additionally, the thesis reviews the current plans for the IFCS software development effort to determine if the MLRS PM is applying the lessons learned from the FDDM in an effort to avoid similar difficulties. In doing so, a comparison of the management approach of the FDDM effort against "modern" software management techniques is made. Because of time and funding limitations, the case study for this thesis was constrained to only the FDDM.

The original FDDM prime contractor was bought out by LVS Corporation. Because of personnel changes resulting from the LVS buy out, and the time that has passed since the FDDM development, contractor personnel were unavailable for information concerning the FDDM. As a result, the FDDM case study relies on information accumulated from Government documentation and interviews only.

2. References and Supporting Documentation

This thesis explores how application of modern software development tools and techniques can significantly improve the management of software design efforts and reduce the software development risks. In the field of management science, much has been written to assist project managers in their understanding of software project management. Organizations such as the Institute of Electrical and Electronics Engineers (IEEE), the Association for Computing Machinery (ACM), and the Software Engineering Institute (SEI) have been instrumental in documenting and defining many of the early problems related to software management. These organizations (along with federal agencies, including the DoD) have produced and published numerous volumes on software development, and have established both industry and DoD standards and protocols. Software development methodologies such as the "waterfall" model (associated with DoD Standard 2167A) and the "Spiral" model (TRW Defense Systems Group), and management evaluations such as the SEI software capability evaluations, have assisted project managers in casting software into a familiar management framework which can be more easily understood and controlled.

For this thesis numerous interviews were conducted, both by telephone and face-to-face, with representatives of the MLRS project management office, the Army Missile Command Software Engineering Directorate, and the Program Executive Office, Tactical Missiles.

D. STRUCTURE OF THE THESIS

This thesis is organized into six chapters, as follows:

Chapter I is the introduction, consisting of a review of the thesis, its relevance and applicability to the DoD, and the scope and structure of the thesis.

Chapter II provides the reader with background information for the FDDM software development case study that will follow. The chapter describes the primary components and a functional description of the FDDM.

Chapter III presents a case study of the FDDM software management decisions prior to 1992 and documents the program achievements from that point through the successful fielding of the system in 1994.

Chapter IV is an overview of the MLRS launcher IFCS software development effort. The overview includes a discussion of the current IFCS program baselines, software development risk areas, and the software development strategy pursued by the MLRS PM.

Chapter V summarizes the lessons learned from the FDDM development effort. The chapter also presents analysis and application of the lessons learned from the FDDM software development effort to determine if these lessons learned are applicable to the IFCS development effort.

Chapter VI provides the conclusions and recommendations, summarizes the FDDM lessons learned, summarizes the IFCS software risk areas, and answers the thesis questions posed in Chapter I.

II. BACKGROUND

This chapter describes how the FDDM was designed to support the Army's fire support operations and provides a functional and operational description of the Fire Direction Data Manager (FDDM) design. The chapter is presented in three sections: a FDDM program overview (including the program development history), a description of the FDDM concept, and a description of the FDDM software components. A summary of the FDDM system operational employment concept is given at Appendix B. Together, this will provide the reader with a detailed background of the FDDM case study presented in the chapter that follows.

A. FDDM PROGRAM OVERVIEW

With the fielding of the Army Tactical Missile System (ATACMS) field artillery units were given a more diverse range of weapons that may be employed on the standard Multiple Launch Rocket System (MLRS). The increased diversity of weapons (and payloads for those weapons) resulted in an increased array of potential targets available to this weapon system. The FDDM was designed to provide enhanced tactical and technical fire support command and control capabilities for MLRS rocket and missile field artillery units located from the division level through the corps Fire Support Elements (FSEs). The requirement for the FDDM is to provide a capability for effective planning and employment of the full range of the MLRS Family of Munitions (MFOM). The MFOM munitions intended to be supported by the FDDM include:

- the MLRS Dual Purpose Improved Conventional Munition (DPICM)
- the ATACMS
- the MLRS Sense and Destroy Armor Munition (SADARM)
- the Tri-Service Standoff Attack Missile (TSSAM), and
- the Brilliant Antiarmor Submunition (BAT) [Ref. 1, p. 1-1]

The need for the FDDM arose from the inadequacies of the existing fire support command and control systems. Neither the MLRS Fire Direction System (FDS) nor the Tactical Fire Direction System (TACFIRE) possessed the capabilities for planning and executing complex missile and rocket artillery fire missions against the increased target base that the ATACMS could strike. [Ref. 1, p. 1-1]

1. History

The following section provides a summary of the key milestones in the development of the FDDM from concept exploration through system deployment.

a. Concept Exploration

During the late 1970's and early 1980's several studies related to field artillery command and control were completed; they include: The Lethal Attack of Emitters Study, The Corps Support Weapons Studies, Counterfire Studies, and Anti-Armor Studies. The following key fire support system requirements were generated by these studies:

- MLRS launcher and MLRS DPICM
- MLRS Terminal Guidance Warhead (TGW) munition
- Joint Tactical Missile System (JTACMS)
- Sense and Destroy Armor (SADARM) munition. [Ref. 1, p. 1-2]

The first requirement to be met was the MLRS with the DPICM (M77) submunition. This system was originally fielded to heavy divisions in a general support (GS) role. Each division was assigned one battery of MLRS launchers within the GS battalion of the division artillery. The MLRS Command and Control system consisted of the M270 launcher with the Fire Control System (FCS) and Fire Direction System (FDS). The role of the FDS was to perform launcher control, tactical fire control, and status reporting. The launcher (with the FCS) performed ballistic computations, aiming, and firing operations. Planning was performed at the division artillery tactical operations center on the Tactical Fire Direction System (TACFIRE) computer. [Ref. 1, p. 1-2]

b. Mission Need

The Army approved development of the ATACMS in 1985 as a replacement for the aging Lance missile system. Field Circular 100-15-1, *Corps Deep Operations*, described the doctrinal concept of employment for the ATACMS. This established a need for a system that could link the locations of high value targets (within the range of ATACMS) with the launcher capable of engaging the target. Overlaying this communication requirement, a new system was needed to control and prioritize the missions of these launchers. The Army's AirLand Battle doctrine placed increased integration requirements on the deep battle. As a result, in 1987 and 1988 the Vice Chief of Staff of the Army ordered two force development test and experimentations (FDTEs) conducted to demonstrate deep battle command, control, communications, and intelligence (C^3I) effectiveness. A significant part of the doctrine that evolved (and ultimately drove the fire support C^3I requirement) was the development of the "decide-detect-deliver" employment doctrine for long range advanced weapon systems. [Ref. 1, p. 1-2]

As more missile and rocket systems were developed, and as MLRS battalions began to be fielded to the Corps artilleries, greater emphasis was placed on the ability to plan and control fires within MLRS. TGW was to begin fielding in 1989, as was AFATDS. The Army Tactical Command and Control System (ATCCS) common hardware was to be available in 1991. The MLRS M270 Family of Munitions (MFOM) and the FDDM were forming a "system of systems" structure that would shape future fire support C^3I operations. [Ref. 1, p. 1-2]

During the approval process for ATACMS, it was determined that AFATDS would not be available for developmental testing (engineering development test - EDT) and initial operational test and evaluation - IOT&E). A device to support the tests of

ATACMS and the conduct of the MFOM FDTE was needed. A decision was made to build a test device, a hybrid consisting of a FDS and the Improved Electronics Unit (IEU) from the M270 launcher for additional data storage, management and communications support. This design was designated the FDDM. A limited number of FDDMs (between seven and nine) were to be developed for use in testing as part of the ATACMS integration contract. [Ref. 1, p. 1-2]

c. Early Development

One of the significant problems with designing the FDDM was that it was required to support operational testing - it was not initially planned to be a development item that would be deployed to Army units. As such, the designers were constrained with presenting the users with a device that would look and act like the device that they would ultimately use in the field. This meant that the battery computer unit (BCU), already developed and fielded as part of the TACFIRE, would have to serve as the "front end" for the device itself. What was really needed was the AFATDS running on the ATCCS hardware - which would not be available in time for the operational testing. [Ref. 1, p. 1-3]

Integration testing conducted in early 1986 revealed that the FDDM with a single IEU would not support all the storage, processing, and communications that were required. A front-end processing unit was needed to manage message traffic and process computational interrupts. What resulted was a three-box system consisting of the BCU components of the FDS, one IEU for data management and storage, and a modified IEU for communication management (designated as the Communications Distribution Unit - CDU). But even this design was found to be insufficient: inadequate CDU throughput, inadequate processing speed, and too many components were among the problems cited by the testers. The ATACMS project management office directed the purchase of a non-developmental item (NDI) to improve on these shortcomings. The Communications and Data Processing Unit (CDPU) - essentially a ruggedized Digital Equipment Corporation

MicroVax - was coupled with the FDS to form a more simplified "two-box" design. During development, it became apparent that a better solution to the BCU would be required. However, there was insufficient time to change the human interface and still meet the test schedule for ATACMS. [Ref. 1, p. 1-3]

d. Requirements Change - a Fieldable System

Based on an announced slip of the AFATDS program in 1987, the Army Deputy Chief of Staff for Operations and Plans (DCSOPS) directed that the FDDM be fielded in limited quantities (31) to forward deployed corps in Europe and Korea until AFATDS was available for transition. At the time, AFATDS was scheduled to be ready for deployment in 1994. The MLRS Project Manager would fund the acquisition of 31 additional BCUs and 31 Fire Direction Adaptation Kits (FDAE). The original configuration of the FDDM was to be made up of the AN/GYK-29 BCU with MLRS/Lance software (Government furnished), an enhancement package (the FDAE) consisting of a CDPU with enhanced software, and ancillary equipment. This was intended to support the additional communications and data processing requirements of the advanced munitions of the MFOM and the doctrinal employment concepts. [Ref. 1, p. 1-3]

As FDDM development proceeded, difficulties continued to be encountered in overcoming shortcomings of the "two box" system interface and in meeting expanding MFOM requirements (the Tri-Service Standoff Attack Missile - TSSAM, and the Ground Launch Tacit Rainbow - GLTR). The BCU was memory, processor, and architecture dependent, and the BCU to CDPU interface was obsolete and very slow. Plans were made to transition the FDDM to the ATCCS common hardware. [Ref. 1, p. 1-3]

In 1987, the decision to field the FDDM as described in Field Circular 100-15-1 resulted from a Deep Battle Review at Department of the Army Headquarters. The Program Executive Office (PEO) Fire Support and PEO Command and Control Systems were tasked to develop a detailed transition plan. [Ref. 1, p. 1-3]

e. Low Rate Initial Production

The FDDM was approved for Low Rate Initial Production (LRIP) in 1989 and type-classified Limited Production Urgent (LPU). However, development/integration of the BCU-based hardware and software was not progressing on schedule, and the FDDM program was cut from the ATACMS IOT&E. This action resulted in the FDDM becoming a stand-alone system which was to progress on a separate development schedule, and be fielded subsequent to the FDDM operations test. The command, control, communications and intelligence (C^3I) demonstration at Fort Sill in September, 1989 confirmed that the planned configuration of the FDDM was not adequate to support the MFOM, and that the BCU should be replaced prior to fielding of the FDDM. It was determined that the BCU should be replaced with an ATCCS common front end processor (Transportable Computer Unit - TCU) to improve processing time and support the enhancement package hardware and software interface requirements. This reconfiguration also included incorporation of an updated MLRS FDS, using the Ada[1] programming language as the operational software for the FDS. The FDDM would have to be fielded in the Standardized Integrated Command Post System (SICPS) or M1068 vehicle. The M1068 is a modified M577A2 tracked vehicle and is the Army's new standard command post. This configuration is being fielded as the baseline MFOM C^3 system until transition to AFATDS. Based on the Army's decision to purchase Lightweight Computer Units (LCUs) (that represent a significant savings to the Army), it was decided in 4th Quarter FY 1992 that the front-end device for fielding would be the LCU. [Ref. 1, p. 1-3]

f. Development Testing

Independent system integration testing (ISIT) was scheduled to assess the tactical operational capability of an FDDM configured with a TCU (as a replacement for the BCU) and integrated into a SICPS. The ISIT consisted of two phases, single thread

[1] Hereafter in this thesis, and throughout the references, this software is referred to as the "Ada FDS software", as compared to the previous, non-Ada software releases of the FDS.

node diagnostic tests, and a user-approved integrated system level, 24-hour operational scenario test based on a modified central European threat. [Ref. 1, p. 1-3]

A pre-ISIT was conducted in the spring of 1991. The test was conducted on tactical equipment with a BCU configuration. Problems were immediately evident, and the scenario was not run past the third hour due to inherent system limitations of the BCU-equipped FDDM. The principle cause of system failure was determined to lie with the message throughput capability of the BCU. [Ref. 1, p. 1-4]

A council of Colonels at Fort Sill directed a limited demonstration to occur using the BCU-based FDDM in July 1991. The purpose of this test was to validate that the BCU-based FDDM could process fire missions for MLRS and DPICM only. The test limitations included non-tactical firing rates, and demonstration of MLRS DPICM and ATACMS only. The fire missions did not demonstrate special access program requirements. Reconfiguration of battery and battalion FDDM was also demonstrated. [Ref. 1, p. 1-4]

The BCU/FDS replacement with the TCU hosting MLRS Ada Version 1 software began formal qualification testing (FQT) in August 1991. The ISIT was completed in December 1991 with the following accomplishments:

- Demonstrated that an FDDM with a TCU front end meets European threat scenario requirements;
- Successfully integrated common hardware and software and SICPS into an M577 command track vehicle. Operated FDDM off of the vehicle's internal power. Successfully deployed and operated a battalion configured vehicle;
- Demonstrated that the FDDM special applications architecture was sound;
- Successfully integrated the MFOM architecture from the Corps FSE down to the M270 launcher and concurrently exercised all unit launchers; and
- Postured the FDDM for a successful customer test. [Ref. 1, p. 1-4]

The FDDM customer test was conducted at Fort Sill with soldiers from the 3rd Battalion 9th Field Artillery in June 1992. The test validated the FDDM training program and allowed soldiers to operate the system in field conditions for four 96 hour scenarios. The system experienced few failures and actually exceeded its mean time between operational failure rate - achieving 317 hours versus a target of 210 hours. [Ref. 1, p. 1-4]

In preparation for the FDDM operational test, the FDDM underwent a series of technical tests. These tests were performed with the LCU as a front end. A FQT and SIT were successfully completed in February 1993. [Ref. 1, p. 1-5]

In addition to the FDDM's technical tests, the FDDM PM felt it was necessary to verify that certain operational capabilities were exercised using tactical equipment prior to operational testing. An independent MFOM integration test (IMIT), which exercised the FDDM C^3 configurations from the launcher through corps FSEs, was conducted in December 1992. [Ref. 1, p. 1-5]

g. Operational Testing and Fielding

The IMIT results demonstrated to the FDDM PM and to the using community that the design of the FDDM system could support the same message load expected in the operational test. The FDDM underwent combined operational testing as part of the TACFIRE Version 10 software OT in the second and third quarters of FY 1993. Fielding of the FDDM to 31 units Army-wide began during the 4th quarter 1993 and concluded in March 1994. [Ref. 8]

A summarization of the FDDM lifecycle is presented graphically on a timeline shown in Figure 3.

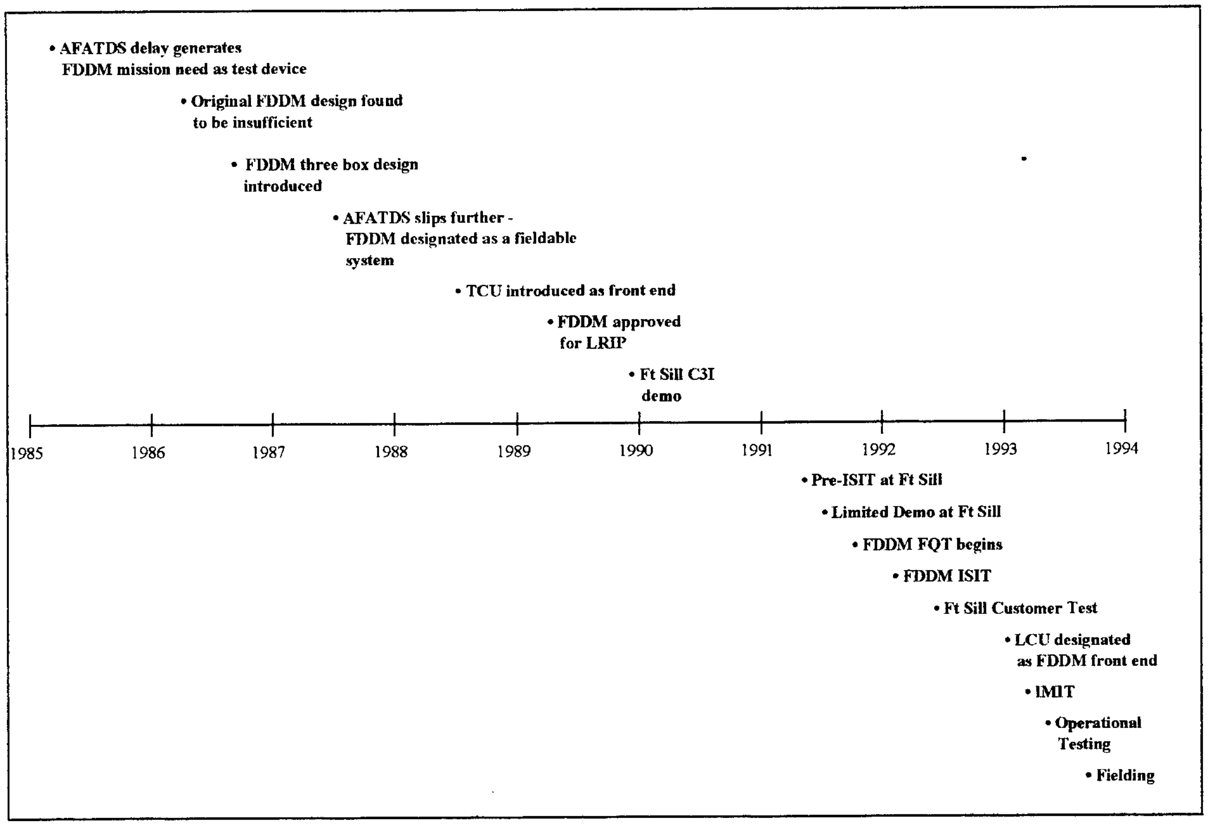

• AFATDS delay generates FDDM mission need as test device
• Original FDDM design found to be insufficient
• FDDM three box design introduced
• AFATDS slips further - FDDM designated as a fieldable system
• TCU introduced as front end
• FDDM approved for LRIP
• Ft Sill C3I demo
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
• Pre-ISIT at Ft Sill
• Limited Demo at Ft Sill
• FDDM FQT begins
• FDDM ISIT
• Ft Sill Customer Test
• LCU designated as FDDM front end
• IMIT
• Operational Testing
• Fielding

Figure 3 - FDDM Lifecycle [Ref. 1]

2. Transition to AFATDS

The FDDM is an interim system pending the fielding of AFATDS. The PEO Tactical Missile Systems (formerly PEO Fire Support) is transitioning the FDDM program to PEO Command and Control Systems for integration into AFATDS Version 3. The transition plan, approved in July 1992, includes four major requirements for incorporation of FDDM into AFATDS:

- Identify unique FDDM requirements that must be incorporated;
- Special application software interfaces;
- Incorporate weapon special applications software; and
- Incorporate utilities special applications software. [Ref. 1, p. 1-5]

B. FDDM CONCEPT

This section presents the FDDM concept by describing the FDDM general concept and components, and operational concept.

1. General Concept and Major Components

The FDDM is fielded in two configurations: a track mounted version for all echelons of selected MLRS units, and a truck mounted version for selected units above the battalion level. The FDDM augments TACFIRE and early versions of AFATDS. It provides a subset of the planned AFATDS functionality for advanced rockets, missiles, and their submunitions. It is also an automated interface and focal point for target intelligence and targeting information gathered from the full range of battlefield intelligence systems. Devices that "talk" in TACFIRE message formats (such as the AN/TPQ-36A Firefinder) can interface with the FDDM. The FDDM components are listed in Figure 4. [Ref. 1, p. 2-1]

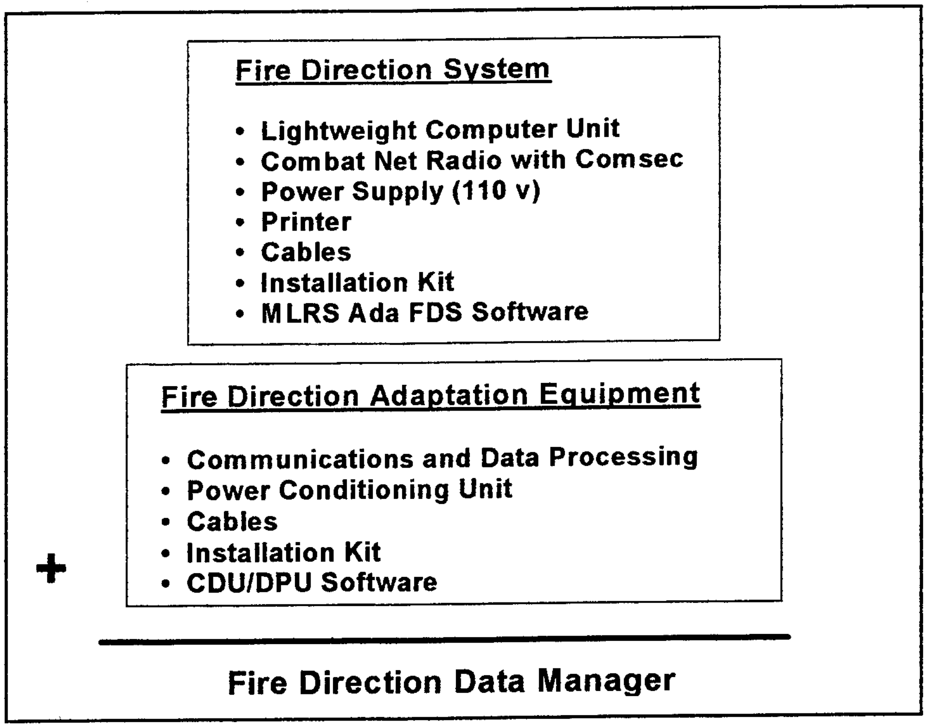

Fire Direction System
• Lightweight Computer Unit
• Combat Net Radio with Comsec
• Power Supply (110 v)
• Printer
• Cables
• Installation Kit
• MLRS Ada FDS Software
Fire Direction Adaptation Equipment
• Communications and Data Processing
• Power Conditioning Unit
• Cables
• Installation Kit
• CDU/DPU Software
+
Fire Direction Data Manager

Figure 4 - FDDM Component Overview [From Ref. 1, p. 2-1]

The Fire Direction System consists of an LCU and the MLRS Ada FDS software. The FDS provides computational and graphical capabilities, and the man-machine interface for the FDDM system. The major components of the Fire Direction Adaptation Equipment (FDAE) are the Communications and Data Processing Unit (CDPU), Power Conditioning Unit (PCU), associated installation cables and the CDU and DPU software. The Program Load Unit (PLU) is available as a special tool for loading and upgrading software systems. [Ref. 1, p. 2-2]

The CDPU consists of a Communications Distribution Unit (CDU) and a Data Processing Unit (DPU). Each of these units is based on the ruggedized MicroVax chassis. The PCU conditions and supplements the power provided by the M577 (command and control vehicle) and can provide temporary power to the CDPU if the vehicle power is not available. The PCU consists of an electronics box and a battery box containing two 12 volt batteries. [Ref. 1, p. 2-2]

Both the CDU and DPU software is written in Ada, and runs on the corresponding unit (either the CDU or the DPU) within the CDPU. The CDU software provides the communications processing logic. The DPU software provides the MFOM specific processing. The DPU software is further divided into a Common Applications Program that provides a set of utilities that are both common and shared by all munitions, and the munition specific programs. [Ref. 1, p. 2-2]

The PLU is included as a basic issue item of the FDDM system and is the same item that is issued to deep attack capable MLRS units as a special tool. Its purpose is to provide the capability to download software and tactical messages from the FDDM to cassettes that can be taken to the M270 launcher for uploading the IEU. Figure 5 shows the total FDDM system configuration. [Ref. 1, p. 2-2]

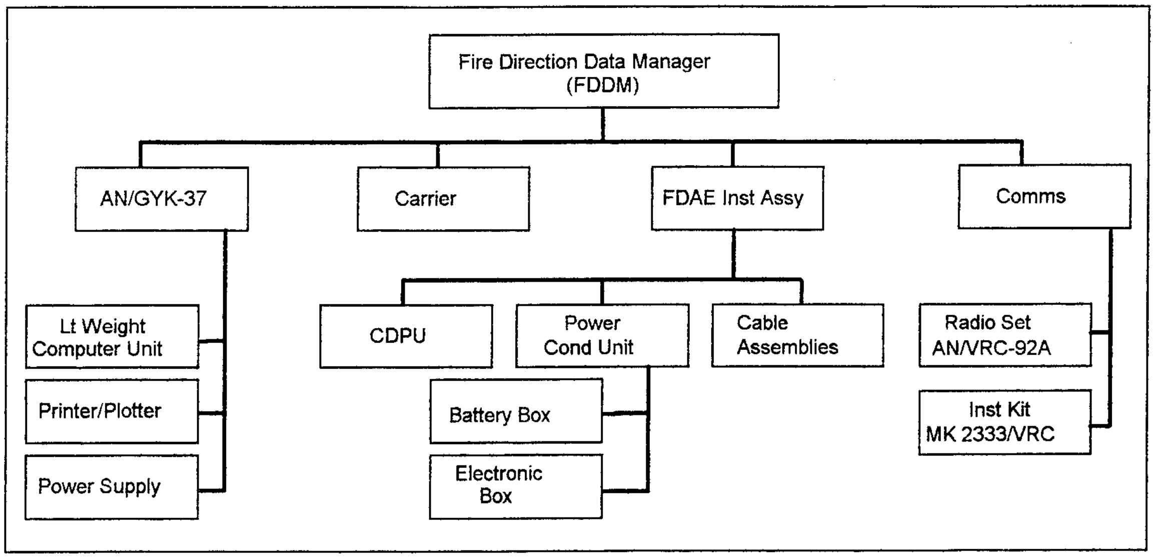


Figure 5 - FDDM System Configuration [Ref. 1, p. 2-6]

2. Operational Concept

The FDDM concept emphasizes distributed MFOM command and control (C^2) operations. Distributed processing involves many different computers and applications executing at different echelons of MLRS within the corps area of operations. The FDDM is capable of configuring its software based on the MFOM payloads that are available to its subordinate units (batteries or launchers) through the use of Special Application Programs (SPAPs). [Ref. 1, p. 2-3]

The same FDDM performs Fire Support Element (FSE), field artillery brigade, MLRS battalion, or MLRS battery functions depending on the operator's input. The FDDM operational concept implements this strategy by standardizing the hardware and software across the various MLRS echelons. Personnel transferred between MLRS echelons should not require extensive training in a new system since they will not be working with a different system, just different functions of the same system. [Ref. 1, p. 2-3]

The FDDM allows either the operator or the computer to set time intervals for the execution of stored time-related fire missions. This capability supports the execution and transmission of large numbers of fire plan targets. A tracking mechanism, accounting "processing time" by large mission and munition, permits the automatic calculation of appropriate application "wake up" times to insure that fire mission time-to-fire, time-on-target, and no-later-than times are met. [Ref. 1, p. 2-3]

The FDDM provides a library of message formats, battlefield geometry, friendly unit position data, targets, fire missions, fire plans, threat information, terrain data, and munitions data. The data stored may include cannon and air asset data as well as rocket and missile data. The FDDM maintains resource status relationship information (i.e., planned fire mission, timed fire missions not in a plan, and available launchers) of assets allocated to tasks for a total of 96 hours (versus the previous 24 hour capability of TACFIRE). Upon demand, a unit's ability to accomplish and plan operations can be calculated and displayed or transmitted. Additionally, "what if" exercises are allowed which will not impact the existing "real" database. An example of this capability would be to enter an additional fire unit and recalculate the schedule of fire to assess the impact. [Ref. 1, p. 2-3]

The FDDM enhances the communications capability and the technical and tactical fire control capabilities of the battalion and battery. The FDDM at the brigade-corps-division echelons emulates the function of the Variable Format Message Entry Devices (VFMEDs) and provides deep fires planning capabilities. The corps MLRS battalions will be the primary delivery units for the MFOM weapons and will provide fires in General Support (GS) of the corps and General Support-Reinforcing (GS-R) to selected division artillery units within the corps area. Under centralized control, the corps FSE, in coordination with the corps tactical operations center support element, will provide target planning and engagement data to the MLRS battalion via TACFIRE/AFATDS on established FM, high frequency, or other communications nets. [Ref. 1, p. 2-3]

Based on the commander's guidance and attack criteria, a "quickfire" channel linking the target acquisition device directly to the MLRS battalion or battery (i.e., decentralized control) may be established to facilitate rapid engagement of certain relevant, high-payoff targets such as theater ballistic missile (e.g., the SCUD missile) launch sites. All that is required to establish this linkage is that the target acquisition device "talk" in TACFIRE message formats. FIREFINDER is one example of a target acquisition device that possesses the capability to interface directly with FDDM. [Ref. 1, p. 2-3]

3. Special Applications Program (SPAP) Concept

The Special Applications Programs (SPAPs) divide the weapon specific processing from the Common Applications (CA) processing software running within the DPU. This architecture is depicted in Figure 6. Each SPAP communicates with the CA software through a structured and documented interface. The *Fire Direction Data Manager Executive Summary* [Ref. 1, p. 2-8] lists the following advantages of this architecture:

a. Real Time Configuration of DPU Software

The user invokes only those SPAPs that are necessary to support the assigned mission. The DPU software runs faster in this configuration than in a configuration that automatically loads all of the software. The faster execution time is due to the reduced number of active programs that have to be serviced by the DPU operating system.

b. Allows Unlimited Number of SPAPs to be Added to the System

The current FDDM architecture allows ten SPAPs to run concurrently. There is no limitation on the total number of SPAPs developed. This approach also allows the development of the CA software package without knowing the requirements of future munitions. This allows the tailoring of munition specific applications as the munition matures into a fielded system.

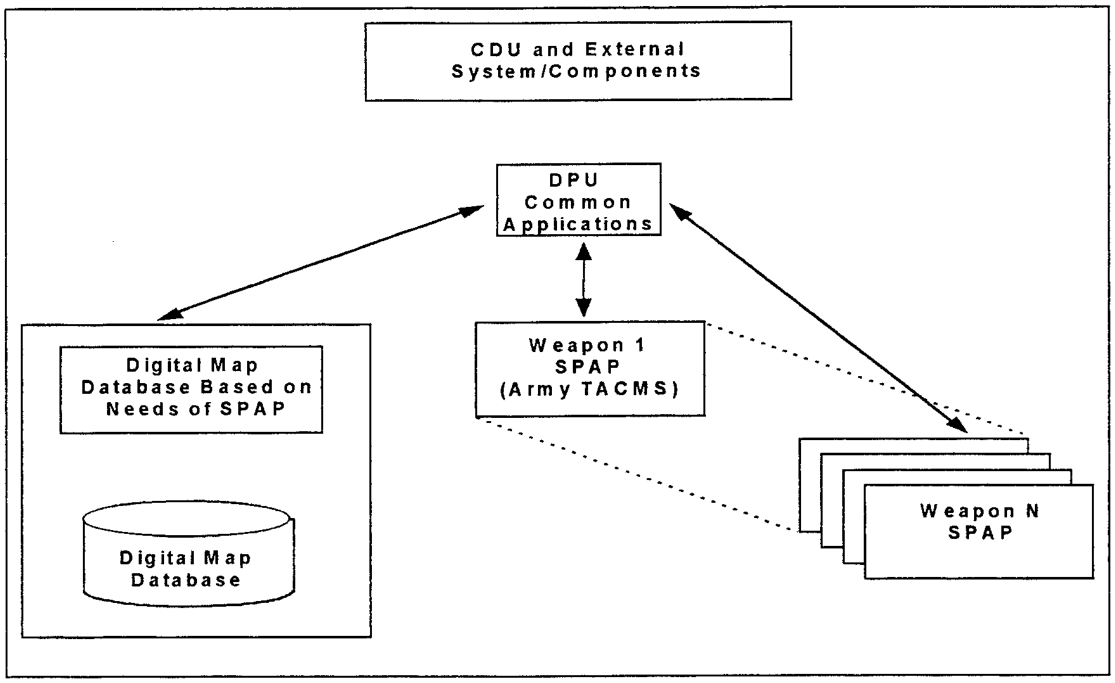

CDU and External System/Components
DPU Common Applications
Digital Map Database Based on Needs of SPAP
Digital Map Database
Weapon 1 SPAP (Army TACMS)
Weapon N SPAP

Figure 6 - Common Applications to Special Applications Architecture [From Ref. 1, p. 2-8]

c. Reduces Costs

The costs of software development and maintenance can be reduced based on reduced lines of code, reduced testing, commonality and reuse of software, and an open-ended architecture:

(1) Reduced lines of code. The number of lines of code developed for a munition are less using the SPAP architecture as opposed to each munition developing its own complete software package. The CA and CDU software are developed once, then the SPAPs only have to develop and maintain munition specific software.

(2) Reduced testing. SPAPs require only a limited amount of testing of non-SPAP software. The SPAP must test the interface with CA, but does not have to test all of the CA software requirements. Due to the interface architecture, which limits the SPAP communications only to those CA relevant to a specific munition,

software problems associated with a SPAP are generally limited within the SPAP interface itself, and not the CA.

(3) Commonality and reuse of software. Each SPAP is forced to use the CA-to-SPAP interface in generally the same way. This approach takes advantage of the software reuse libraries concept that the Ada programming language provides. This will tend to lead to a common approach to future SPAP architectures. This common approach will reduce the number of personnel required to maintain the software. This also will allow future munitions to build on the proven concepts/architectures of existing SPAPs by reusing previous SPAP designs.

(4) Open-ended architecture. Allows the FDDM to be fielded without knowing what the detailed requirements are for future munitions. The CA-to-SPAP interface is flexible enough to allow the development and integration of new SPAPs after the initial development of the current FDDM software. [Ref. 1, p. 2-9]

C. FDDM SOFTWARE DESCRIPTION

The significant FDDM software components are the MLRS Ada software, the Communications Distribution Unit (CDU) software, and the Data Processing Unit (DPU) software. The FDDM also has low-level device handling software and firmware, but these are not addressed in this thesis.

1. MLRS Ada FDS Software

The MLRS Ada FDS software runs on the Lightweight Computer Unit (LCU). The purpose of the MLRS Ada FDS software is to provide tactical and technical fire control at the various echelons of field artillery rocket and missile units. As employed at selected MLRS battalion and battery echelons in the FDDM configuration, the MLRS Ada FDS software provides the SPAP fire control capabilities as in the stand-alone FDS. The Ada FDS software also provides additional capabilities required for the CDPU interface and the deployment of the MFOM. [Ref. 1, p. C-1]

2. Communications Distribution Unit Software

The CDU software runs on the CDPU's CDU main processor. The purpose of the CDU software is to provide external message reception and transmission, and internal message distribution for the FDDM. The CDU software initializes the CDU software and hardware, establishes and maintains communications with external and internal FDDM interfaces, verifies and processes messages, and provides built-in test (BIT) capabilities. [Ref. 1, p. C-1]

3. Data Processing Unit Software

The DPU software runs on the CDPU's DPU main processor. The purpose of the DPU software is to receive, process, and transmit data through the CDU to the LCU or remote subscribers. The data contains information concerning fire units, ammunition, and targets. The DPU, using weapon special application programs, processes fire missions for the specified munition and target. Additionally, the DPU software schedules time-related missions prior to the target becoming an active fire mission. In this way, the DPU software is used for management of fire support assets and battle planning. [Ref. 1, p. C-1]

The DPU software consists of several software packages that can be run simultaneously on the CDPU's DPU main processor. Common Applications are run in the DPU to support the SPAPs. The following describes each of the DPU software packages.

a. Common Applications

The Common Applications (CA) initializes the DPU software and hardware, establishes and maintains communications with the CDU, provides a set of common utilities that weapon SPAPs processing require, and provides built in test (BIT) capabilities. The following are the major common utilities that CA provides:

- Maintains databases containing information about units, munitions, and tactical plans/situations;
- Activates SPAPs programs as needed;
- Provides software utility libraries for math and character functions; and
- Provides generic fire mission planning and execution. [Ref. 1, p. C-1]

b. Digital Map

In order to meet the special data requirements of enhanced systems, computer software within the FDDM must be able to access terrain elevation data. This requirement has been identified as the Defense Mapping Agency (DMA) Level I Digital Terrain Elevation Data (DTED). To provide the DTED, the CDPU requires the DMA program to access processed DTED from external media, select the data for a defined area, and transfer that data to the internal storage device. The DTED is placed on external media using the DTED compressor utility. The operator requests the DTED of a specified area to be loaded onto the internal storage device (removable hard drive) so that other special applications programs may access the data. The digital map SPAP, associated programs, and data files reside on the internal storage device for immediate processing of requests for elevation data. [Ref. 1, p. C-2]

c. ATACMS

The ATACMS SPAP provides critical information through a series of messages that assist the commander in the planning and employment of ATACMS. The ATACMS SPAP provides the FDDM operator with ATACMS effects, number of rounds to fire, missile location and altitude. Missile location and altitude information facilitates air space coordination with the Air Force (a deficiency identified during Desert Storm operations). The ATACMS weapon has extended range capabilities that can be exploited using an extended range algorithm provided by the ATACMS SPAP. The ATACMS SPAP is envisioned being employed only at the C^2 node (corps FSE) responsible for planning ATACMS missions, but can easily be provided to lower echelons if operationally required. [Ref. 1, p. C-2]

d. Generic Weapon

The Generic Weapon (GW) SPAP is used to simulate future munition special applications for testing purposes. The following are some of the ways that the GW SPAP may be used to support testing:

- Exercise the DPU CA software interface;
- Simulate the processing required by future weapons; and
- Simulate additional MFOM weapons during field testing. [Ref. 1, p. C-2]

This chapter presented background information including the FDDM program overview, the program history, a description of the system operational concept, and the FDDM system software. Additional information describing the operational employment concept of the FDDM is given at Appendix. The chapter that follows will present a case study of the events and conditions leading up to the 1992 GAO report on the FDDM.

III. CASE STUDY OF THE MLRS FDDM SOFTWARE DEVELOPMENT

In May 1992, the General Accounting Office released its report, *Software Development Problems Delay the Army's Fire Direction Data Manager*. The report cited software performance problems, schedule delays, and cost overruns as summarized by the following:

> Due to software development problems, FDDM software is not complete, the prime contractor's development costs have tripled from $8 million to over $24 million, and the program is more than 2 years behind schedule. Existing software problems that need to be corrected before FDDM is deployed could push costs and completion dates even further from original projections. [Ref. 2, p. 1]

This chapter provides a case study of the FDDM software management decisions prior to 1992, and documents the program achievements from that point through the successful system fielding in 1994.

A. CASE BACKGROUND

This section provides further background to the FDDM software development case study in addition to that introduced in the previous chapter. The development timeframe, program management structure, and development strategy will be discussed.

1. Development Timeframe

The FDDM was originally intended as a "hybrid test device" to support the operational testing of the ATACMS. Because of this, neither a mission needs statement nor operational requirements document were written to document the early system requirements. The test device, designated as the FDDM in 1986, was needed to mimic the command and control operations of AFATDS, which would not be available to support the ATACMS operational testing in 1990. The "hybrid" design consisted of the existing MLRS FDS and a modified IEU (from the M270 launcher) with the software resident on the IEU principally for the handling of message traffic. A firm-fixed-price contract was awarded to the MLRS launcher's prime contractor in 1986 to develop and build seven FDDMs at a price of approximately $8 million. Delivery of these systems was required to coincide with the ATACMS operational testing in 1989. [Ref. 8]

Following significant technical requirements changes resulting from the designation of the FDDM as a fieldable system in 1987, the FDDM development schedule was released from the ATACMS operational test schedule and progressed as a stand-alone system. Fielding of the FDDM as an interim system for the AFATDS was scheduled to take place in 1993, subsequent to ATACMS operational testing. [Ref. 1, p. 1-3]

2. Program Management

The FDDM (as originally intended) was designed as a modification to existing MLRS field artillery command and control devices to support the ATACMS operational testing. Government management of the development effort resided within the MLRS PM office because of their experience with MLRS hardware and relationship with the MLRS launcher's prime contractor. Funding for the FDDM development came from the ATACMS test budget. Both the MLRS project office and the ATACMS project office were assigned to the Program Executive Office for Fire Support (now Tactical Missiles), located at Redstone Arsenal, Alabama. [Ref. 8]

In 1987, the AFATDS PM announced a further slip in schedule that indicated that AFATDS would not be available when ATACMS was fielded. In order to keep the ATACMS program on schedule (with operational testing in 1990 followed by deployment in 1991), the Army Deputy Chief of Staff for Operations directed that the FDDM be fielded in limited quantities (31 systems) as an interim for the AFATDS. This decision also required that FDDM support other missiles and munitions which were under development at that time. [Ref. 1, p. 1-3]

In order to support development of the FDDM as a fieldable system that would support not just ATACMS but BAT, SADARM, and TSSAM as well, the MLRS PM formed a product management office to oversee the FDDM. The M270 Family of Munitions Command, Control, Communications, and Intelligence (MFOMC^{3}I) Product Manager[1] position was created within the MLRS project office to provide this program oversight. The product management office consisted of the MFOMC^{3}I PM (a US Army lieutenant colonel) with matrix support tasked from the MLRS project office. An organization chart depicting the FDDM product management office structure and its relationship to the MLRS PM office is shown in Figure 7. [Ref. 8, I]

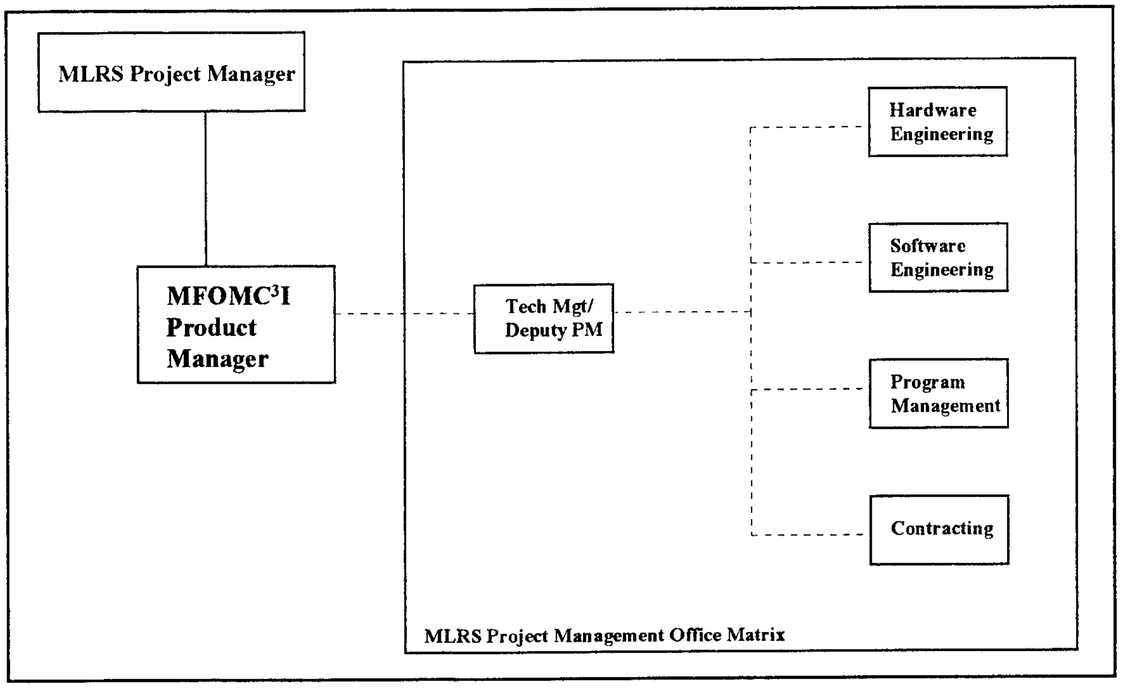


Figure 7 - FDDM Product Management Office Structure

3. Development Strategy

The original FDDM development strategy was very limited. At the time, it was believed (by both the Army and the prime contractor) that the basic (i.e., "two box") design for the FDDM could provide the command and control requirements for the ATACMS operational testing with minor modifications and limited development testing.

[1] Throughout the literature and this thesis, the title "MFOMC^{3}I PM" is referred to simply as the "FDDM PM". The FDDM development effort was the primary role of the MFOMC^{3}I PM.

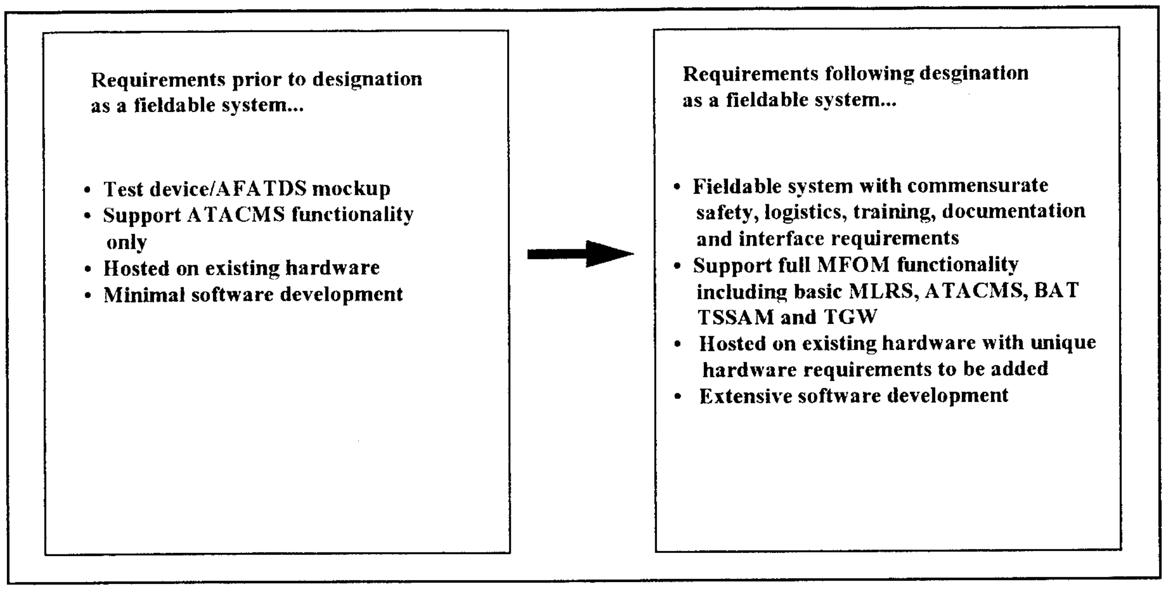
For this reason, the FDDM development was not tracked and reported under the requirements of DoD Standard 1521B, *Technical Reviews and Audits for Systems, Equipments, and Computer Software*. According to LTC Mario Cervantes, the most recent FDDM product manager:

> At the time, the FDDM was not a product; it was a test device to support ATACMS. We used a fixed price contract with (the prime contractor) that said, basically, 'Modify this government furnished equipment and write a small piece of software that will do what AFATDS is supposed to do for ATACMS'... We weren't really interested in how (the prime contractor) did it, so long as they got it done on time. ...the MLRS PM had a number of contracts open at any given time that didn't report under (DoD Standard) 2167A or 1521B. [Ref. 8]

When the requirement for the FDDM changed from that of a test device for ATACMS to a fieldable system supporting all of the munitions in the MFOM, the FDDM PM took steps to formalize the FDDM oversight structure with the prime contractor. A series of government-supervised development tests and demonstrations were scheduled to determine the feasibility of the existing design against the growth in requirements to support the additional munitions. These tests indicated that the planned FDDM hardware configuration could not support the requirements of the additional munitions in the MFOM.

As summarized in Figure 8, at this point the accumulation of changes to the FDDM requirements essentially constituted a change in scope. The FDDM was no longer to be a test device to support ATACMS only for operational testing, but a fieldable system required to support the basic MLRS functionality as well as ATACMS, BAT, TSSAM, and TGW. [Ref. 10]

Because of the significant hardware and software development complications resulting both from the requirements growth and the changes required for a fieldable system, and based on the poor testing results achieved up to that time, the FDDM was separated from the ATACMS operational test schedule in October 1989. [Ref. 1, p.1-3]



Requirements prior to designation as a fieldable system...

- Test device/AFATDS mockup
- Support ATACMS functionality only
- Hosted on existing hardware
- Minimal software development

Requirements following desgination as a fieldable system...

- Fieldable system with commensurate safety, logistics, training, documentation and interface requirements
- Support full MFOM functionality including basic MLRS, ATACMS, BAT TSSAM and TGW
- Hosted on existing hardware with unique hardware requirements to be added
- Extensive software development

Figure 8 - Summary of FDDM Requirements Changes

Because the FDDM had become a fieldable C^3I system, instead of a missile test device, the FDDM PM consulted with the US Army Communications and Electronics Command (CECOM) Fort Sill Center for Software Engineering beginning in late 1989. The Fort Sill Center is the Army's experts for development of fire support software C^3I systems, and would ultimately be the life cycle software support center for the FDDM. In June 1990, the Fort Sill Center contracted with Telos to assist the FDDM PM in an independent verification and validation (IV&V) capacity. Information regarding the FDDM software development (to include subsequent software release packages) were forwarded through the Fort Sill Center to Telos. In this way, Telos was given progressive release packages of the FDDM software to evaluate. [Ref. 8]

The firm-fixed-price nature of the original FDDM contract bound the prime contractor to continue performing under the terms of the contract. While the changes mentioned previously amounted to a change in scope [Ref. 10], this was not contested by the prime contractor. Rather, as a result of mutual consent by both the Government and the prime contractor, the original contract was repeatedly modified to encompass the additional requirements. These changes, plus the addition of Telos as an IV&V

contractor, greatly increased the price of the FDDM development (discussed in greater detail in the following section). [Ref. 8]

Throughout 1990, the prime contractor continued to experience software development difficulties with the data processing software and, according to the FDDM PM, "...was considerably behind schedule." [Ref. 8] The Fort Sill Center advised the PM that Telos (the IV&V contractor) was confident that they could complete the data processing software development and deliver the full FDDM functionality "...within six to twelve months." [Ref. 10] Telos had considerable experience in developing other fire support command and control software systems, and further benefited from their collocation with the Fort Sill Software Development Center and the user community (the US Army Field Artillery School).

In March 1991, the FDDM PM accepted the latest incremental release of the FDDM software from the prime contractor. This release, designated as package 8, was tested informally during a preliminary independent system integration test (pre-ISIT). The pre-ISIT identified numerous problems with the data processing software, and the test had to be canceled in July 1991 due to incompleteness of the software. [Ref. 2, p. 6]

In August 1991, the FDDM PM granted a conditional release of the package 8 software to the Fort Sill Center for Software Engineering. The Fort Sill Center in turn contracted with Telos for final development of the FDDM software. The Fort Sill Center was well positioned to assume control of the remaining FDDM software development as a result of its involvement in reviewing the software progress from the prime contractor for the previous twelve months. [Ref. 10]

The FDDM PM did not terminate the original contract with the prime contractor. Following conditional acceptance of the package 8 software release, the PM allowed the contract with the original prime contractor to expire. As mentioned previously, the remaining software development was performed by the Fort Sill Center. An additional contract (cost plus incentive fee) was subsequently awarded to Codar for production of hardware and the remaining FDDM integration effort. [Ref. 8, 19]

The Fort Sill Center for Software Engineering significantly accelerated the FDDM software development strategy by incorporating a series of rapid prototyping demonstrations with the user community from Fort Sill. The Fort Sill Center established a software development facility for the FDDM on site by installing the prototype FDDM hardware and downloading the conditionally released FDDM software (package 8) from the original prime contractor. Software engineers from Telos worked directly with representatives from the Fort Sill user community to find and fix the remaining FDDM software problems. Representatives of the US Army Missile Command Software Engineering Directorate and the Fort Sill Center Staff maintained configuration control throughout the "test-fix-test" cycles. [Ref. 11]

In December 1991, an ISIT was conducted at Fort Sill, Oklahoma. This test demonstrated the basic FDDM functionality while identifying 30 additional software trouble reports (STRs) [Ref. 11]. These STRs were subsequently identified and fixed by Telos, and in June 1992, the FDDM PM conducted a successful customer test that demonstrated significantly better mean time between operational failure rates than required (317 hours versus 210 hours required). [Ref. 1, p. 1-4]

In May 1993, the FDDM underwent combined operational testing as part of the TACFIRE Version 10 operational testing at Fort Sill, Oklahoma. The following summary was extracted from the conclusions and recommendations paragraph of the FDDM conditional release approval based on the interim abbreviated operational assessment, performed by the Army's Operational Evaluation Command (OEC):

> Overall Conclusions. Operationally, the FDDM is marginally effective and marginally suitable. The FDDM effectively replaces the functions of the currently fielded FDS as a command and control system, however, has shortcomings in providing some of its enhanced capabilities. The most significant problems were in processing fire plans and transmitting weapons effects data for special applications. Workarounds have been identified for these effectiveness shortcomings. Deficiencies in TM (technical manual) coverage of error warning messages, lack of collective training, and poor printer performance are the most significant problems in relation to system suitability. [Ref. 12, attachment E]

The conditional release of the FDDM was principally due to existing shortcomings in several classified weapons SPAPs. According to the FDDM PM, these shortcomings had no effect on the ATACMS or MLRS DPICM SPAPs, but were sufficient to warrant the system description as "marginally effective". Because none of these classified systems had yet been fielded, and because of the modular design of the SPAP architecture, there was no reason to withhold fielding of the FDDM in the interim. The performance difficulties of each of these SPAPs was corrected or resolved in the six months following the conditional release.[1] [Ref. 8]

The test results were found to be sufficient to grant conditional release of the FDDM and are summarized by the FDDM PM in the following:

> The May OT (operational test), the FDDM's most important test of the year, took place using US Army soldiers in a tactical environment at Fort Sill, Oklahoma. As a subset of the TACFIRE Package 10 OT, the FDDM very successfully participated in phases III and V of a five part test. The third phase consisted of an FDDM system test and the fifth phase tested the FATDS system's ability to interface with one another.
> [Ref. 13, p. 5]

In August 1993, the MICOM Materiel Release Review Board (MRRB) conditionally approved the FDDM for fielding. The package was forwarded to the US Army Materiel Command (AMC) where release was approved in September 1993. [Ref. 13, p. 5]

Materiel release approvals at MICOM and AMC were the last steps necessary for tactical fieldings to begin. The contractor had been prepared to start equipment installations and the ceremony to hand off the first tactical FDDM to the 75th Field Artillery Brigade took place on 27 September 1993. The FDDM initial operational capability (IOC) occurred with the fielding of the 6th Battalion, 27th Field Artillery

[1] Following several "neck down" decisions by the PEO Tactical Missiles and at the order of the Assistant Secretary of the Army, Research, Development, and Acquisition, the TSSAM, TGW, and GLTR programs were canceled or significantly restructured as of June 1992. This obviated the need to incorporate these requirements into the FDDM SPAPs. [Ref. 16]

Battalion, at Fort Sill on 28 October 1993. At the conclusion of fieldings in July 1994, a total of 31 tactical FDDM systems had been fielded. [Ref. 13, p. 5,6]

This section consisted primarily of a more detailed background of the history of the FDDM and the management decisions that led to the successful fielding of the system in 1993 and 1994. In the next section, the software development, project cost, and project schedule problems experienced by the FDDM program prior to May 1992, will be discussed in greater detail using the May 1992 GAO report as a guide.

B. SOFTWARE DEVELOPMENT PROBLEMS, SCHEDULE DELAYS, AND COST INCREASES

The purpose of this section is to document the software development, project cost, and project schedule problems experienced by the FDDM program as of May 1992 (the date of the GAO report on the FDDM). The references for this section are the GAO Report to the Chairman, Subcommittee on Research and Development, Committee on Armed Services, House of Representatives, *Embedded Computer Systems: Software Development Problems Delay the Army's Fire Direction Data Manager* [Ref. 2] and the formal response sent from the FDDM PM (via the Fire Support PEO) to the Office of the Under Secretary of Defense for Acquisition[3] [Ref. 14].

1. Software Development Problems

The GAO report states that the FDDM development effort had encountered a number of software development problems since 1986. The software development problems were demonstrated at key program test and demonstration points cited by the GAO report as follows: the decoupling of FDDM from ATACMS operational testing in 1989, preliminary independent systems integration testing (pre-ISIT) in March 1991, fire

[3] These two documents are henceforth referred to as "the GAO report" and "the PM's response".

direction and data processing data base synchronization, and problems uncovered during the FDDM ISIT in December 1991. [Ref. 2, p. 6,7]

a. Decoupling of FDDM and ATACMS Operational Testing

The first significant example of the FDDM's software development problems, as cited by the GAO, was the failure of "...a critical field test in 1989" that led to the system's exclusion from the ATACMS operational testing. [Ref. 2, p. 6] The "critical field test" was the C^3I demonstration conducted at Fort Sill, Oklahoma in September 1989 [Ref. 1, p. 1-3]. According to the GAO report, the cause of this testing failure was that "...its (the FDDM) communications software would not work and had to be rewritten and its data-processing software was not completed in time to be used in the field test - and was unable to support the missile's (ATACMS) operational tests held later that year." [Ref. 2, p. 6]

The PM's response to this issue states that the C^3I demonstration was intended to test the capability of the FDDM hardware configuration with the original BCU front end. Since the purpose of these tests was primarily testing of the hardware configuration, the data processing software was not planned as part of the test. [Ref. 14, p. 2] The Army was considering replacing the BCU with an alternative, the TCU (transportable computer unit) common hardware. These tests validated that the BCU was insufficient as a front-end processor for the FDDM. [Ref. 1, p. 1-3]

According to the FDDM product manager, the data processing software was not complete at the time of the C^3I demonstration. The last of the C^3I demonstrations was canceled due to unavailability of the data processing software. This was the primary reason that the FDDM was decoupled from the ATACMS operational testing. [Ref. 8]

b. Pre-ISIT in March 1991

The pre-ISIT is addressed in the GAO report as follows:

> In March 1991, preliminary integration testing was performed on updated data-processing software. However, the software was still

incomplete. It could not run the approved test procedures and had to be modified before testing could be resumed. In July 1991, the Army had to cancel this testing because the fire direction system did not have the capacity to handle high volumes of messages, and the system would therefore shut down. [Ref. 2, p. 6]

The PM's response states that the pre-ISIT was conducted as a "...series of test-fix-test cycles" intended to find problems with the software. The PM's response attributes "a significant number of the issues" associated with this test to the BCU front end processor. According to the PM's response, the Army had already decided to use the TCU front end (now the LCU) as the front end for the FDDM. [Ref. 14, p. 2]

c. Fire Direction and Data Processing Data Base Synchronization

According to the GAO report, the pre-ISIT uncovered difficulties in keeping the fire direction and data processing data bases synchronized during fire missions. Without this synchronization, the data processing system would not have accurate data on launcher status and assignments. [Ref. 2, p. 6]

The PM's response states that the synchronization problems were attributable to the use of the BCU during these tests. The TCU, with larger memory and faster processing power, overcame the problems associated with data base synchronization in later tests. [Ref. 14]

d. Problems Uncovered During the December 1991 ISIT

The GAO's review of the December 1991 ISIT indicated that a number of FDDM's software problems had not yet been addressed. The GAO report states that, during periods when high firing rates were required, the data manager experienced communications bottlenecks due to the large number of messages being transmitted.
[Ref. 2, p. 7]

The PM's response indicates that the bottlenecks were the result of intentionally stressful test scenarios that were designed to test the FDDM to its operational limits.

According to the PM, the ISIT tests showed that the FDDM exceeded its message handling requirements, as evidenced by the following statement:

> ...the FDDM exceeded its required mission rate and that the bottlenecks only occurred in planned overstress test environments designed to find such bottlenecks. In the ISIT, the FDDM met the fire mission processing requirements of the European scenario which had a considerably higher fire mission rate than the Post Cold War mission scenario. [Ref. 14, p. 2]

2. FDDM Development Costs

The GAO reported that the costs to develop the FDDM had increased from $8 million in 1986 to an estimated $50 million by 1992. According to the GAO report:

> Because the original FDDM contract did not require separate identification of software development costs, it is difficult to estimate exact costs or cost growth. However, the Army estimates that original contract costs have increased from $8 million to about $24.5 million, with most of these increases due to added requirements. In addition, the Army has spent another $25 million beyond its original estimate to contract for services such as engineering assistance, and independent verification and validation. [Ref. 2, p. 7]

According to the PM's response, the development costs for the FDDM grew for the following reasons:

> FDDM costs have grown as reported. However, changes in the mission and planned FDDM utilization have been the driver. The FDDM was originally contracted as a demonstration/test device to provide command/control interface during development testing of the Army's suite of long range missiles and smart munitions. When the Army decision was made in 1987 to upgrade the FDDM into a fieldable system to support the ATACMS missile, as well as the other missile systems under development at that time, the mission requirement and associated costs of the FDDM were raised significantly. The change to a fielded system added previously unfunded requirements for documentation, environmental protection, qualification testing, logistic support, and the other requirements associated with fielding a system. These requirements significantly raised oversight requirements and therefore the support services cost. [Ref. 14, p. 3]

3. FDDM Development Schedule

The GAO report states that the Army intended the FDDM to be ready by 1989 in order to support the ATACMS operational tests. The FDDM did not support the ATACMS operational testing, nor was it ready for ATACMS fielding in 1990. While the missile can function without the FDDM, it cannot be fired rapidly when needed. By 1990, the planned deployment date for the FDDM had been further slipped to January 1993. The GAO report further states:

> The contractor delivered communications software in May 1991, but due to software problems the Army postponed the delivery date for the data-processing software until May 1992. Without the data-processing software, FDDM is not functional. As of April 1992, FDDM was still undergoing development and testing, and the Army had delayed FDDM deployment from January 1993 to June 1993. [Ref. 2, p. 7]

The PM's response states that the software had completed all testing and had met the requirements necessary to support a fielding decision. The reason the deployment date was slipped ten months was "...to take advantage of a 60% production cost savings obtained by using the latest version of the Army common hardware computer, the Lightweight Computer Unit (LCU)." [Ref. 14, p. 3]

The GAO report included remarks concerning the FDDM PM's decision to transition the system software development management to the Fort Sill Center for Software Engineering. The GAO report indicated concern for the system schedule in light of the switch to a different contractor, as illustrated by the following:

> This organization (the Fort Sill Center), however, is not using the original FDDM contractor and has brought in another contractor (Telos). The new contractor is familiar with some of the FDDM system but will have to learn how all the FDDM components work together before solving FDDM's existing problems, and completing FDDM testing may affect FDDM's deployment schedule. [Ref. 2, p. 7]

According to the PM's response, the Fort Sill Center had been identified previously as the life cycle software support center for the FDDM and had been receiving completed work packets from the prime contractor throughout development. The PM defended his decision to transition the final development of the FDDM to the Fort Sill Center as follows:

> The product office directed the FDDM designated post deployment software life cycle support center to take over the software development under the product office's management. This decision was made because of the new contractor and the need to get the software on schedule. The new contractor (Telos) was considered a positive move because of their demonstrated performance. The results of this move have been that the software development was completed on schedule and successfully tested during the June 1992 customer test. [Ref. 14, p. 4]

C. FDDM SOFTWARE DEVELOPMENT MANAGEMENT

The GAO report stated that the FDDM software development suffered from poor management, as exemplified by the following extract from the GAO report:

> Many of FDDM's problems have occurred because the Army did not effectively manage the FDDM software development effort. Specifically, it did not provide detailed requirements in the original 1986 contract or promptly enforce Defense standards for software development, and it continued to add functional requirements that further delayed development. The contractor added to these development problems with poor testing in some areas. [Ref. 2, p.8]

This section addresses management issues associated with the FDDM software development. The discussion will be presented through a review of the following GAO findings: that the FDDM functional requirements were not well-defined or controlled, that Defense standards were not enforced, and that contractor testing was inadequate and delayed development. Though not addressed by the GAO report, this section will also discuss the prime contractor's software development capability and its sufficiency in meeting the requirements for the FDDM.

1. FDDM Functional Requirements Definition/Control

The GAO report states that the Army did not provide sufficiently detailed functional requirements in the original 1986 contract. Poor functional requirements definition was cited by the prime contractor's software development manager as "...the major problem with FDDM development." Between 1986 and 1991, the Army continued to add requirements, which required additional software development. These additions were principally to support additional weapon systems that the FDDM would control. According to the GAO report, "The first FDDM product manager agreed that the additional requirements caused delays in the development schedule." [Ref. 2, p. 8]

The PM's response states that the "additional requirements" were actually "...a complete change in the mission and objective of the FDDM system." [Ref. 14, p.4] This period is consistent with the timeframe when the FDDM went from that of a test device to a fieldable system (1987). As the GAO report states, these additions incorporated the additional weapons and munitions that the FDDM would support in a fielded environment.

An additional complicating factor associated with the requirements growth experienced by the FDDM was the nature of the new weapons being incorporated during this period. At the time these requirements were generated, the TSSAM, BAT, and Ground Launch Tacit Rainbow (GLTR) programs were special access programs (SAP), commonly referred to as "black programs." Design information, requirements, and weapon characteristics were restricted information. According to Mr. Raymond Pietruszka, lead engineer for the FDDM, this made incorporation of the programs into the FDDM more challenging, as indicated by the following:

> First of all, we didn't even know about these programs, or know who they were, or where they were at. One day, a guy comes in, briefs us, and says, 'Sign this piece of paper.' Now we have to incorporate this into our design. But, we couldn't just pick up a phone and call a SAP program and have them tell us what we needed to know. Just trying to get together for a meeting would take weeks. And then, at the meeting, their engineers would say something like, "We can't tell you about that, you don't have access to that area." [Ref. 10]

This view was confirmed in an interview with Mr. George Williams, Program Executive Officer (PEO) for Tactical Missiles (formerly Fire Support). Mr. Williams agreed that a substantial portion of the development problems encountered in the MFOM integration effort in general, and the FDDM in particular, was attributable to the restrictions required in SAP programs. [Ref. 15]

2. Enforcement of Defense Software Standards in FDDM Development

The GAO report states that the Army required the contractor to follow DoD Standard 1521 (Technical Reviews and Audits for Systems, Equipment, and Computer Software) during the software development effort, "...but did not promptly enforce its provisions." According to the GAO, this allowed the Army to increase requirements without controls established by an approved baseline. The GAO report also cites a requirement in DoD Standard 2167 (Defense System Software Development) for a software development plan (SDP). According to the GAO, the contractor did not have a detailed SDP to guide development of the software. [Ref. 2, p. 8]

According to the PM's response, formal specification reviews (such as the software specification review required by DoD Standard 1521) were not required for the original FDDM contract. The PM's response states the following:

> ...in-depth reviews were held for each software specification to insure that both the contractor and Army understood the requirements. While the data processing software specification was not signed by the government until 1989, interim approval had been given to the contractor at the preliminary design review of each software package. [Ref. 14, p.6]

The PM's response states that the Army did not require incorporation of DoD Standard 2167 into the original FDDM contract because "...it had not been incorporated into the MICOM contracts at that time." This oversight was corrected later with the development of the data processing software, and with the transition to the Fort Sill Center, which implemented DoD Standard 2167 for the FDDM. [Ref. 14, p. 6]

3. Inadequacy of Contractor Testing

The GAO report states that development was delayed because numerous problems were not detected during the contractor's initial testing. A specific example of the inadequacy of the contractor's testing, as cited by the GAO, was the contractor's use of hard wired communications in testing where radio link communications were called for in the system test. [Ref. 2, p. 9] According to Mr. Pietruszka, who was present at this test, the communications failure could have been avoided by testing the system in the lab before the demonstration. Mr. Pietruszka states:

> The problem with this test was that the modem they (the contractor) installed was too sensitive for use in the noisy FM environment. The modem kept keying on background noise, which would lock up the system. It took us two weeks to figure that one out...all we had to do was reduce the sensitivity of the modems and the problem was fixed. But we didn't find this until we were out on the ranges of Fort Sill...if they (the contractor) had tested their modems in the lab with FM, like they were supposed to, this would have been found earlier. [Ref. 10]

4. Contractor's Software Development Capability

Throughout numerous interviews conducted as research for this thesis, government program management officials associated with the FDDM expressed their belief that the contractor did not possess the capability to develop the FDDM software once the requirements changed from a test/demonstration device to a fieldable system. While some of the remarks may be attributable to a defense of the PM's decision to transfer software development to the Fort Sill Center (and the new contractor, Telos), the consistency of the remarks is pertinent to a discussion of the FDDM's software management decisions.

When asked whether the FDDM would have been successfully deployed if the Army had stayed with the prime contractor, LTC Cervantes, the FDDM PM responsible for the decision to move the FDDM to the Fort Sill Center, replied as follows:

> The FDDM would not have made the progress it did, in the timeframe we were working. After giving the work over to the Fort Sill Center, we had maybe six months until the ISIT. When we came through that test (in December 1991) with only a few problems remaining, I thought, 'this is it...we've turned the corner.' You see, this was the very first success that FDDM had; this was the light at the end of the tunnel.

> Would we have been there if we had stayed with (the prime contractor)? No. I don't think so. [Ref. 8]

Mr. Pietruszka stated the following concerning the software capabilities of the prime contractor:

> The (prime contractor) is the expert when it comes to working on the (MLRS) launcher and the launcher hardware. They were the right guys for the job when the FDDM was nothing but an IEU and FDS. But when the requirement changed to a command and control device for the MFOM, they were out of their league. They just didn't have the software experience to do the job. [Ref. 10]

According to Mr. James Steelman, a systems engineer assigned to the Fire Support PEO staff during development of the FDDM, the prime contractor did not have the software capability necessary for the FDDM effort. His remarks included the following:

> (The prime contractor) gained a lot of software experience on the FDDM, and the government paid for that experience. They got smart on Ada and we got smart on software in general... I don't think it was just requirements changes that made it tough for the contractor - they didn't have the people and they didn't have the experience that was needed on that program. [Ref. 16]

D. FDDM-AFATDS INTEGRATION EFFORT

Since 1987, when the Army decided that the FDDM would be a fielded system as an interim for the AFATDS, the FDDM has been required to integrate many of the AFATDS requirements for advanced missiles and munitions. Because of this, the Army has planned to transition the FDDM software into the AFATDS software beginning in 1994. According to the GAO report, as of January 1992, the Army had not made formal plans for a detailed integration of the FDDM software into AFATDS. The GAO report states that a formal transition plan is necessary "...to determine how much FDDM software will be compatible with AFATDS and how much new software will have to be written." [Ref. 2, p. 10]

According to the PM's response, the strategy to transition the FDDM software to AFATDS is as follows:

> First, the TRADOC (Training and Doctrine Command) System Manager for Fire Support Command and Control Systems (TSM-FSC2S) has developed a set of user functional descriptions for the FDDM. Second, PM FATDS, PM MLRS and TSM-FSC2S have agreed to a transition plan. Key actions in the plan are for PM FATDS to perform a requirement trace between the FDDM software, user requirements, and AFATDS, insuring AFATDS Version 2 supports the future incorporation of the FDDM into AFATDS Version 3 and establishing a management structure to oversee the process. [Ref. 14, p. 8]

LTC Mario Cervantes, the most recent FDDM PM, when interviewed for this thesis in July 1994, indicated that the integration effort was progressing well, as indicated by the following:

> Our plan was to 'grow' the FDDM requirements into the AFATDS in Version 3 starting in Version 2. So far we've been able to do that principally because the FDDM code is written in Ada and is modular. A good deal of credit, though goes to the people at the Fort Sill Center (for Software Engineering) who worked with us and the AFATDS PM in tracing the requirements from our product to theirs...their (the Fort Sill Center staff) knowledge of Fire Support requirements is key to making the transition work. [Ref. 8]

The AFATDS is currently scheduled for initial operational test and evaluation (IOT&E) beginning in August 1995. According to the current product manager for AFATDS, the FDDM integration effort has proceeded as planned and will not delay the expected fielding or functionality of AFATDS. [Ref. 17]

E. GAO CONCLUSIONS AND RECOMMENDATIONS

The GAO report concluded that the increased costs and schedule delays were the result of the Army's failure to follow required development procedures. In addition, the GAO report states that the change in software contractor and new software requirements may affect the planned June 1993 deployment of the FDDM. According to the GAO, additional delays would limit the useful life of the FDDM. [Ref. 2, p. 11]

The GAO recommendations to the Army concerned the PM's strategy for integration of the FDDM into the AFATDS, and included the following:

- Provide direction for determining how much, if any, of the FDDM software can be used in AFATDS;
- Establish clear lines of authority and accountability between the FDDM and FATDS offices for making decisions and resolving problems; and
- Provide specific milestones for actions to accomplish the transition.

  [Ref. 2, p.11]

The PM's response indicates that "not using proper procedures" caused some of the increased costs and schedule delays, but was "not the sole reason", as indicated by the following:

> In addition to not using proper procedures, the FDDM was affected by the dynamic environment of the period in which several new weapons systems were added to the MFOM, each adding or changing requirements, and the delays experienced by AFATDS which change the very role the FDDM was to play. [Ref. 14, p. 8]

The PM's response defends movement of the software management responsibility to the Fort Sill Center and the selection of Telos as the contractor for FDDM software in the following:

> While factors beyond the control of the product office may impact the fielding of the FDDM, it will not be its software. The change in contractors has proved to be the best action possible under the condition with the result that the FDDM completed a highly successful customer test in June of 1992. [Ref. 14, p. 8]

F. SUMMARY

The GAO report [Ref. 2] was published in May 1992. Up to that point, the FDDM program had exhibited numerous software problems including the following:

- After numerous tests and demonstrations, the FDDM software was still not complete;
- The prime contractor's costs had tripled from \$8 million to more than \$24 million, and the Army had committed an additional \$25 million for engineering services and support contracts; and
- The FDDM program was more than two years behind schedule and had been decoupled from its original mission of supporting the ATACMS operational testing.

The GAO report attributed the majority of the FDDM software development problems to a failure by the Army to follow required procedures. [Ref. 2] The FDDM PM's response stated that, while the Army's failure to follow procedures contributed somewhat to the FDDM's difficulties, the principal reason for the FDDM's development problems was the result of the change in role and mission of the FDDM. [Ref. 14] Government officials associated with the FDDM development effort indicated that the prime contractor did not possess the software capability to develop the FDDM software when the requirement changed from a test device to a fieldable C^3I system. [Refs. 8, 10, and 16] The Army's position is that moving the software development from the original prime contractor to the Fort Sill Center (for software development) and Codar (for hardware production and integration) was in the best interest of the FDDM program at that time. These actions ultimately resulted in the successful customer test in June 1992.

In the following chapter, the MLRS PM's development strategy for the Improved Fire Control System (IFCS) will be reviewed. Similarities and differences between the software development strategies of the FDDM and IFCS will be highlighted in subsequent chapters to evaluate the application of lessons learned from the FDDM development effort.

IV. THE MLRS IMPROVED FIRE CONTROL SYSTEM DEVELOPMENT

In November 1992, the MLRS project office awarded a sole-source, cost plus award fee (CPAF) contract to Loral Vought Systems Corporation (LVS) for the engineering and manufacturing development (EMD) phase on a comprehensive upgrade to the existing fire control system (FCS) of the MLRS launcher. The upgrade program, designated as the improved fire control system (IFCS), will modernize the MLRS launcher and provide it with improved C^3I capabilities for operations in deep fire missions on future digitized battlefields.

The IFCS design is a combination of both hardware and software improvements. The primary focus of this chapter is a description of the IFCS embedded software development strategy. While the chapter culminates in a description of the IFCS embedded software development program, the reader will first be given an understanding of the overall system development, including the hardware design. The discussion in this chapter is presented in the following order: the IFCS program background, a description of the IFCS which details its major hardware and software components, and specific details of the IFCS software development strategy. In the chapter that follows, the IFCS software development strategy will be evaluated against the lessons learned from the FDDM software development.

A. BACKGROUND

This section provides the reader with background information concerning the IFCS program. The background is presented in the following order: the IFCS requirement; a general, system-level description of the IFCS; the IFCS development schedule; and a description of the IFCS management structure and acquisition strategy.

1. IFCS Requirement

The original design of the MLRS launcher is nearing 15 years of age. The MLRS development program was originally proposed in the mid-1970s to counter the "...massive Warsaw Pact forces arrayed against the NATO forces in Europe." Design of the MLRS proceeded throughout the 1970s and was finalized at the DSARC IIIA decision in November 1982. A full-scale production contract was awarded to the initial source in December 1982. [Ref. 18, p. I-1, C-8]

Since 1982, the FCS of the MLRS launcher has undergone minor product improvements to improve component reliability, availability, and maintainability (RAM) factors. But little has been done previously to modernize the original design to provide the compatibility needed in terms of data processing speeds, throughput, and flexibility necessary to keep the launcher current with evolving fire direction systems and future MLRS munitions. [Ref. 7]

The existing FCS on the MLRS launcher is based on early 1980's digital and analog technology. The Intel Z80, 8080, and 8088 microprocessors used in the system have reached their maximum potential. Also, the existing architecture does not support the standard word sizes that evolving fire direction systems will require (e.g., 32 bit messaging modes). As a result of this, the existing FCS will soon be considered obsolete by the Army. [Ref. 9]

In considering the requirement for an upgrade to the FCS, the MLRS PM has focused on future requirements for digital data transmission and processing. As the Army moves forward in its initiative to digitize the battlefield, the MLRS launcher will have the flexibility to operate with the Army's future data interchange protocol. Currently, the IFCS file transfer protocol will use the Transmission Control Protocol - Internet Program (TCP-IP). Should the Army protocol change or differ from that currently being pursued by the IFCS PM, the IFCS protocol can be modified using software. [Ref. 19, p. 19]

The reduction of operations and support (O&S) costs represents an additional requirement for the IFCS. The IFCS design is intended to reduce the number and skill level of system maintainers and improve the reliability and maintainability of the launcher. Additionally, with the costs of military-specification hardware costs increasing (due to a decline in the size of the military industrial base) the IFCS will save on the cost of spare parts through the use of commercial standards in an "open" architecture. According to the IFCS product manager, the IFCS enhancement (when fielded with a parallel program, the improved launcher mechanical system - ILMS) will save approximately $250,000 per MLRS battery per year. [Ref. 9]

2. IFCS System Description

The IFCS is being developed as a major product enhancement to the existing MLRS launcher. The IFCS operational environment is depicted in the IFCS system level diagram shown in Figure 9. The following is extracted from the general description of the IFCS as provided by the IFCS system specification (commonly referred to as the "A" specification):

> The IFCS enables the MLRS Family of Munitions (MFOM) to interoperate with national fire direction systems. The IFCS shall support this MFOM with the addition of the appropriate missile/rocket manager out of the munition, launcher, or fire direction system employed...The IFCS shall have the on-board capability to conduct built-in test (BIT), receive a fire mission, navigate/determine launcher location, compute firing data, orient on the target, and fire the selected weapons. [Ref. 19, p. 8]

The IFCS design stresses the use of common hardware, software, and standardized interfaces. The "open" nature of this architecture is intended to negate system obsolescence or dependence on a specific technology. As fire support technologies mature, the IFCS is intended to grow to accommodate future requirements. This is accomplished primarily through the distribution, or modularity, of the overall system architecture. The following excerpt describes this architecture in greater detail:

> The IFCS implementation shall utilize common hardware, software, and interfaces in all line replaceable unit (LRU) designs. LRUs shall allow for technology insertion which mitigates obsolescence and promotes

growth. Data buses, buses, processors, and memories shall be implemented using controlled standards and military qualified electronic components...All circuit card assemblies (CCAs) used to implement identical or common FCS functions (e.g., MIL-STD-1553 interface, Institute of Electrical and Electronics Engineers (IEEE) 802.3 interface, power conditioner modules, processor CCAs, memory CCAs, etc.) shall be common and interchangeable between LRUs. [Ref. 19, p. 11]

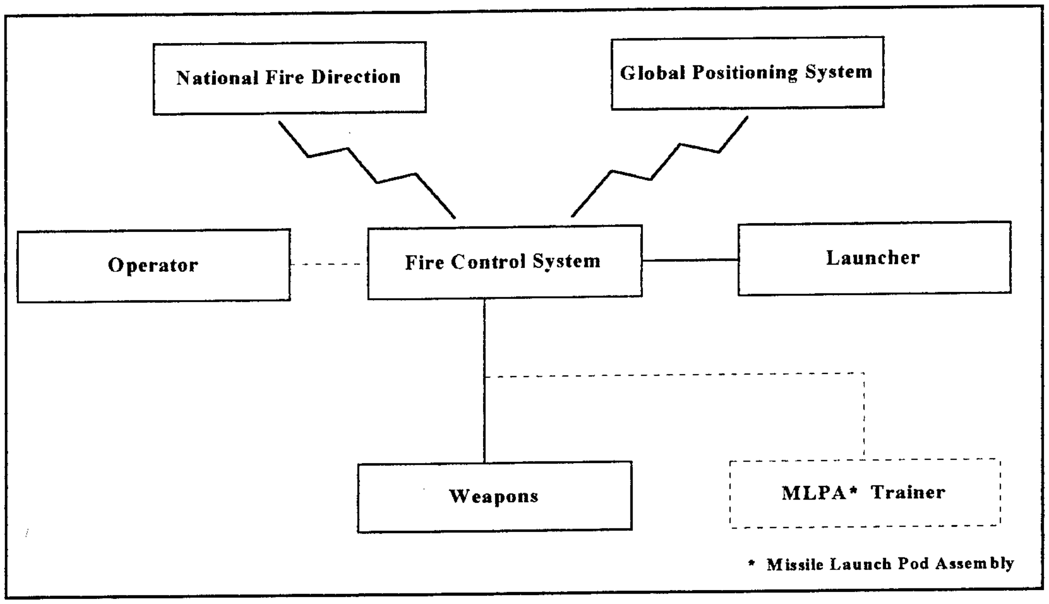


Figure 9 - IFCS System Diagram [From Ref. 19, p. 9]

The IFCS functional diagram listing the principle hardware and software components is shown at Figure 10. IFCS software components are listed in Figure 11. A description of each of these components will be presented in a later section.

3. IFCS Development Schedule

The IFCS program received approval to enter the EMD phase in November 1992. A hardware preliminary design review (PDR) and the system design review (SDR) were concluded during 1993. In fiscal year 1994, the system specification review (SSR), hardware critical design review (CDR), and software PDR were completed. Currently, the IFCS program is undergoing engineering design tests. The software CDR will lock in the CSCI designs in August 1995. The complete IFCS development program schedule is shown at figure 12. [Ref. 9]

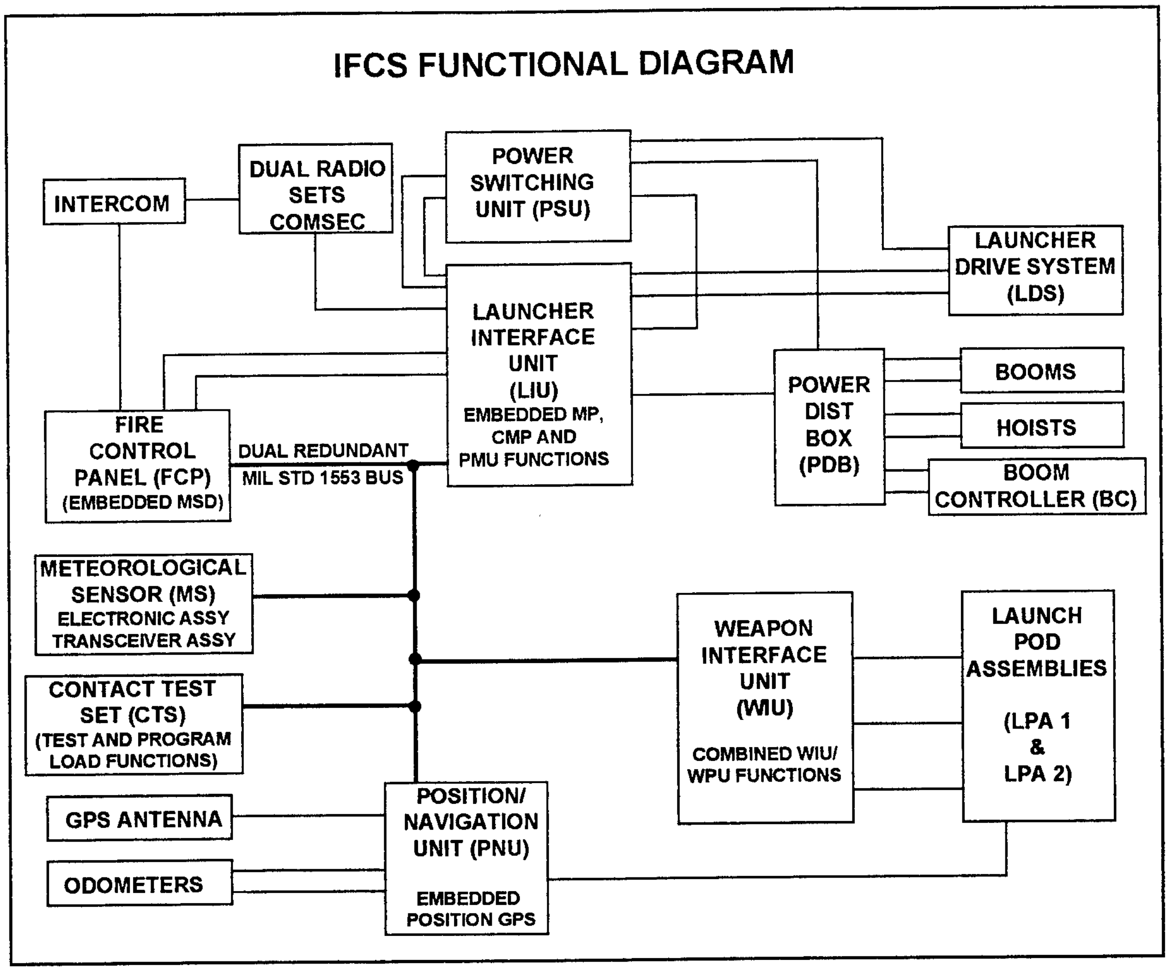

IFCS FUNCTIONAL DIAGRAM
INTERCOM
DUAL RADIO SETS COMSEC
POWER SWITCHING UNIT (PSU)
LAUNCHER DRIVE SYSTEM (LDS)
LAUNCHER INTERFACE UNIT (LIU) EMBEDDED MP, CMP AND PMU FUNCTIONS
POWER DIST BOX (PDB)
BOOMS
HOISTS
BOOM CONTROLLER (BC)
FIRE CONTROL PANEL (FCP) (EMBEDDED MSD)
DUAL REDUNDANT MIL STD 1553 BUS
METEOROLOGICAL SENSOR (MS) ELECTRONIC ASSY TRANSCEIVER ASSY
CONTACT TEST SET (CTS) (TEST AND PROGRAM LOAD FUNCTIONS)
WEAPON INTERFACE UNIT (WIU) COMBINED WIU/ WPU FUNCTIONS
LAUNCH POD ASSEMBLIES (LPA 1 & LPA 2)
GPS ANTENNA
ODOMETERS
POSITION/ NAVIGATION UNIT (PNU) EMBEDDED POSITION GPS

Figure 10 - IFCS Functional Diagram [From Ref. 19, p. 10]

IFCS Software Components

- Communications Management
- Launcher Interface
- Maintenance Management
- Man/Machine Interface
- Missile/Rocket Manager
- Missile/Rocket Ballistics Manager
- Position/Navigation
- Power Management
- Weapon Interface
- FCS Institutional Trainer

Figure 11 - IFCS Software Components [Ref. 19, Section 3.2.2.2]

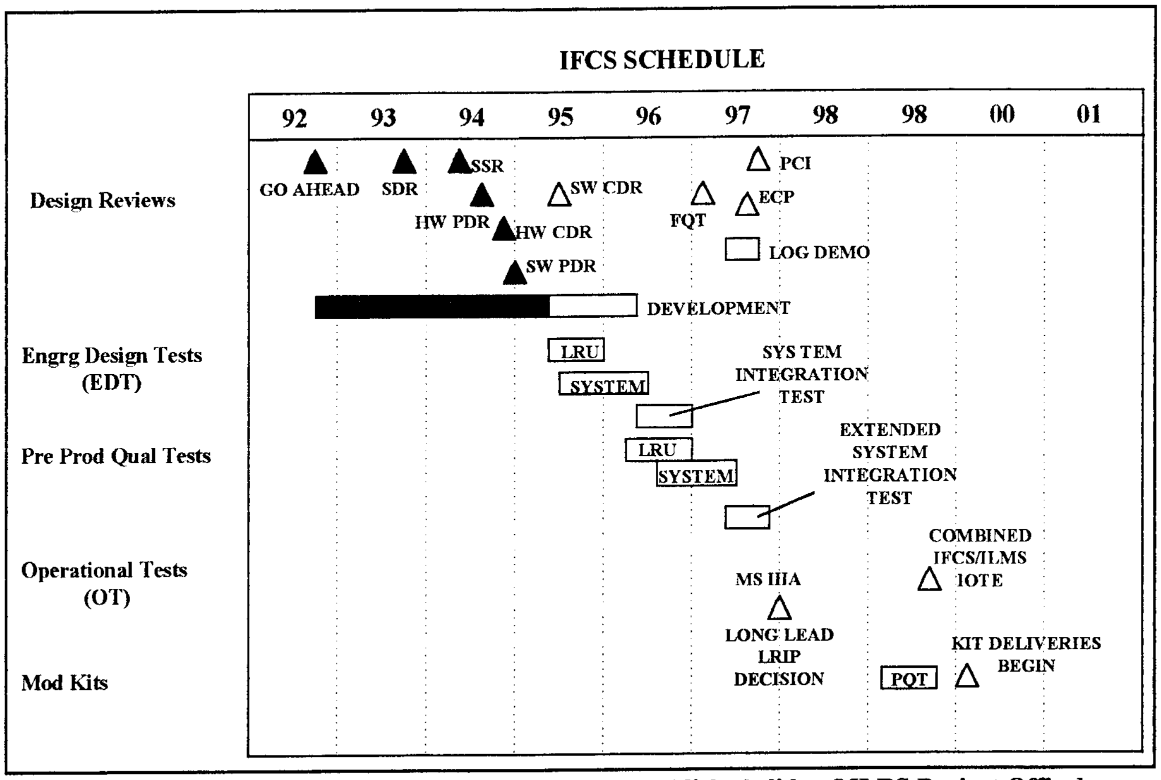


Figure 12 - IFCS Development Schedule [From unpublished slides, MLRS Project Office]

The IFCS program will run concurrently with the improved launcher mechanical system (ILMS) program scheduled to begin in August 1995. The ILMS program will upgrade the launcher's mechanical systems at the same time the IFCS program modernizes the launcher FCS. The IFCS will be incorporated into the MLRS launchers using modification kits. Currently, the MLRS PM is uncertain whether the overhaul kits will be installed at unit locations or at depot maintenance facilities. The kit installations and ILMS overhauls are scheduled to begin during the third quarter of fiscal year 2000. [Ref. 9]

4. IFCS Management Structure and Acquisition Strategy

The IFCS is a major product improvement to the existing MLRS launcher, and is considered an acquisition category (ACAT) III program. The system development is being managed by the MLRS Project Management Office within the Program Executive

Office, Tactical Missiles, at Redstone Arsenal, Alabama. An Army system product manager position has been created for this system, and is currently filled by a GM-15 civilian Department of the Army centrally-selected product manager. [Ref. 9]

The Government IFCS product management team is similar to the former FDDM product management structure. The IFCS PM office consists of the product manager with matrix support from the MLRS project office. The current product manager is the former deputy/chief of technical management from the FDDM program. Hardware, software, contracting, and program management support is supplied by the MLRS PM matrix staff from the ground support branch, software engineering branch, acquisition management branch, and program management staff, respectively. [Ref. 9]

The prime contractor and integrator for the IFCS is LVS, located in Dallas, Texas. The Government issued a CPAF contract, with a maximum price of $137 million, to LVS for the EMD phase of the IFCS development. LVS has subcontracted to Raytheon for the meteorological sensor, and Allied Signal for the position and navigation unit. Total procurement authority for the IFCS program is currently estimated at $750 million. The procurement strategy for the IFCS has not yet been published. [Ref. 9]

B. DESCRIPTION OF THE IFCS COMPONENTS AND FUNCTIONS

This section describes in greater detail the function of the IFCS components (referred to as line replaceable units, or LRUs) and computer software configuration items (CSCIs). The primary reference for this section is the system specification for the IFCS (reference 19). The descriptions presented are extracted from the paragraphs that specify the system components' requirements allocation (for LRUs), and the segment definitions (for CSCIs). The discussion addresses the hardware components first, followed by the software components (CSCIs).

1. IFCS Hardware Components

This section describes the functions and requirement allocations for the primary LRUs in the IFCS.

a. Fire Control Panel (FCP)

The primary purpose of the FCP is to provide the man/machine interface (MMI) function for the IFCS. The FCP will consist of a display, alphanumeric keypad, toggle switches, and light emitting diode (LED) indicators. The display will be capable of providing the operator with both alphanumeric and real time video information. Because the MLRS is an international program, the display and keyboard must be capable of being configured in multiple languages. All IFCS functions will be controlled through the FCP. These include system power, resource allocation, communications, and fire mission control. [Ref. 19, p. 22]

b. Main Processor (MP)

The MP provides general purpose processing capability for the implementation of a missile/rocket manager, resource management, MMI processing, maintenance processing, and other control functions. The MP is housed in the launcher interface unit (LIU) and interfaces directly with the IEEE 802.3 and MIL-STD-1553 buses. [Ref. 19, p. 27]

c. Communications Processor (CMP)

The CMP is the communications interface between the FCS and the combat radio networks. The CMP will include programmable modems capable of baud rates up to 19,600 bits per second, and must also support two-wire land line communications. The CMP will interface with the FCS using both the IEEE 802.3 and MIL-STD-1553 buses. The CMP functionality is combined with the MP in the launcher interface unit (LIU). [Ref. 19, p. 29]

d. Position Determining and Navigation Unit (PNU)

The PNU has two primary functions: control of the launcher aim for firing operations, and determination and report of launcher location. The PNU will consist of a global positioning system (GPS), ring laser gyros, and accelerometers. For firing operations, the PNU will provide position, attitude and angular rate data required to aim the launcher loader module (LLM) to a given azimuth and elevation. Additionally, the PNU will stabilize the LLM prior to, during, and following firing operations, then retarget the LLM for different aiming parameters. For position determination and reporting, the PNU is required to provide the launcher's position, direction of travel, rate of travel, and elevation. The PNU will interface directly with the MIL-STD-1553 and IEEE 802.3 buses for position and navigation updates to the FCS. [Ref. 19, p. 29]

e. Meteorological Sensor (MS)

In addition to firing missiles, the MLRS fires standard rockets in a ballistic mode without mid-course correction. Because of this, the launcher aim must compensate for the effects of wind speed and temperature. The MS provides both wind speed and direction, and atmospheric temperature to the FCS for these ballistic computations. The MS interfaces directly with the FCS through the MIL-STD-1553 bus.

f. Power Management Unit (PMU)

The PMU manages the FCS and launcher drive system (LDS) direct current (DC) power. The PMU will function under software control to direct power to each LRU as necessary. In addition to power switching devices, the PMU will also provide general purpose processor CCAs with nonvolatile memory for the power control software. The PMU will interface directly with the IEEE 802.3 and MIL-STD-1553 buses for communication with the FCS. [Ref. 19, p. 41]

g. Launcher Interface Unit (LIU)

The LIU serves as the interface between the FCS and the launcher loader module (LLM). The primary function of the LIU is to direct the specific boom and hoist operations of the launcher, as directed by the FCS. The LIU must also function in a manual mode in the event that the FCS or primary controls are disabled. The LIU is required to interface with the MIL-STD-1553 bus and provide general purpose processing capabilities. [Ref. 19, p. 37]

h. Weapon Interface Unit (WIU)

The primary functions of the WIU are to test and fire the weapons in the launch pod assemblies. The testing functions determine both the availability and readiness of a weapon to be fired, as well as the "safe" status of a weapon. The firing capability involves the direction of power through the interface cable to a specified weapon's firing squib. Because the MLRS is capable of firing different types of munitions, each with different firing and safety specifications, the WIU is required to be software reprogrammable for specific munitions. This necessitates that the WIU have a general purpose processing capability with random access memory (RAM), and interface directly with both the IEEE 802.3 and MIL-STD-1553 buses.

i. Weapon Power Unit (WPU)

The WPU provides power to the weapons loaded into the launch pod assemblies (LPAs). The primary functions of the WPU include power control, weapon preparation and readiness, and mine setting. The WPU interfaces directly with the LPAs and the MIL-STD-1553 and IEEE 802.3 buses.

j. Mass Storage Device (MSD)

The MSD will be the primary nonvolatile storage device for the IFCS. The proposed design for the MSD is a shock-isolated, removable hard disk drive with one gigabyte of storage capacity. [Ref. 20] The MSD will be housed in the same chassis as the FCP and will interface with the FCP using a small computer system interface (SCSI). [Ref. 19, p. 44]

k. Contact Test Set (CTS)

The CTS is the primary direct support maintenance diagnostic tool for the FCS. The CTS will interface through the launcher control unit (LCU) with the MIL-STD-1553 and IEEE 802.3 buses. The primary purpose of the CTS is error detection and fault isolation within individual LRUs. [Ref. 19, p. 44]

2. IFCS Software Components

This section describes the IFCS software components (CSCIs) and details the requirements allocated to software within the operational segments defined in the IFCS system specification.

a. Communications Management

This function manages all digital communications for the FCS and allows the operator and the FCS to report status. The communications management functions include the following: background BIT (built in test) capability (CMP status), database communications management, emission control, operational transition reports, and digital fire missions. The communications manager will be hosted on the launcher interface unit (LIU). [Ref. 19, p. 78]

b. Launcher Interface

The launcher interface provides a standard interface between the FCS and the launcher. The launcher interface will be capable of aiming the LLM to an aimpoint, reporting launcher status and health, preventing firing in a "no-fire" zone, preventing movement of the LLM into a damage zone, maintaining LLM position, and reporting

LLM azimuth and elevation. The launcher interface will be hosted on the launcher interface unit (LIU). [Ref. 19, p. 78]

c. Maintenance Management

The maintenance function manages all maintenance specific operations including: maintenance of an activity log, CCA stored faults, CTS operations, LRU and fuse tests, LRU activity logs, and maintenance software. The maintenance function will be hosted on the FCP, but is capable of operating through either the FCP or the CTS. [Ref. 19, p. 79]

d. Man/Machine Interface

The man/machine interface (MMI) provides the single interface between the operator and the FCS. The MMI controls the digital map for the operator, and ensures that from the operator's perspective, every fire mission "looks" the same. The MMI must be reprogrammable to account for a multilingual user base and be capable of displaying many languages and alphabets. Specific MMI capabilities include the following: FCS configuration, command operations, communications map, fire mission control, meteorological data, position and navigation data, LRU information, map format and control, activity logs, and video displays. The MMI will be hosted on the FCP. [Ref. 19, p. 80]

e. Missile/Rocket Manager

The missile/rocket management function is responsible for managing the weapon payload to support the FCS. During fire missions, the missile/rocket manager sequences the launcher to execute the mission. A separate missile/rocket manager will manage each weapon. This function's capabilities will include the following: arm weapon, fire mission control and editing, weapon firing, weapon loading, countdown sequencing, hang-fire and hold-fire alarms, and weapon communications. The missile/rocket manager will be hosted on the weapon interface unit (WIU). [Ref. 19, p. 78]

f. Missile/Rocket Ballistics Manager

The missile/rocket ballistics management function is responsible for managing and performing the weapon ballistics computations. This function is a companion to the missile/rocket manager. A separate ballistics computation manager is expected for each weapon type. This function's capabilities include amendment of meteorological data, latitude domain, and aimpoint ballistics. This software, along with the companion missile/rocket manager, will be hosted on the WIU. [Ref. 19, p. 81]

g. Position/Navigation

The position/navigation function provides the FCS with positional and attitude information. The primary reference for this function is the inertial navigation system; the secondary reference is GPS. The position/navigation capabilities include the following: GPS attitude determination, location initialization, position of launcher, position of LLM, POS/NAV attitude and slew rate determination, and background BIT (POS/NAV status). The position/navigation software will be hosted on the PNU. [Ref. 19, p. 83]

h. Power Management

The power management function provides the FCS with the capability to switch power to any LRU. This function will include the following capabilities: abort, CMP power only, CTS connected, LRU on/off, PMU check, power indicator, power saver mode, and reboot/restart. This function will be hosted on the PMU. [Ref. 19, p. 83]

i. Resource Management

The resource manager is responsible for managing the FCS resources (i.e., software, memory, fire mission initiation and sequencing). This function supports the following capabilities: activity log, addressable memory programming, resource allocation, background BIT (MP, MS, and MSD status), system clock, communications log, fire mission schedule, initialization of fire missions, missile/rocket manager loading, local meteorological, reconfiguration, reinitialization, LLM reloading, fire missions storage, system initialization, and read/write CCA faults. This function is hosted on the FCP. [Ref. 19, p. 83]

j. Weapon Interface

The weapon interface is responsible for managing the power, data, mine setting functions, fuse setting functions, status, and squib lines between the FCS and the weapon pod. This function includes the following capabilities: fire rocket, fuse setter test, identify launch pod assembly, mine setter, power data, set fuse, set mine, WPU/WIU commanded BIT, and background BIT (WPU/WIU status). The weapon interface is hosted on the WIU. [Ref. 19, p. 84]

k. FCS Institutional Trainer

The FCS institutional trainer (FIT) will provide the interface to the six gunner stations for the instructor console and give the instructor the ability to conduct training classes. The FIT capabilities will include the following functions: record, store, fault insertion, scenario, start/stop/send FM radio transmission, and view station.
[Ref. 19, p. 85]

This section provided additional background information about the specific components and functions of the IFCS hardware and software. In the next section, the IFCS software development strategy will be discussed.

C. IFCS SOFTWARE DEVELOPMENT STRATEGY

The preceding sections of this chapter described the IFCS program, the system functions, and the IFCS hardware and software components. This section describes the IFCS software development strategy. The section is presented in five parts, as follows: a description of the software development effort, a discussion concerning the software acquisition strategy and contractual features, a description of the post deployment software support (PDSS) requirements, software testing, and software quality assurance.

1. Software Development

The IFCS software development strategy is being managed and reported in accordance with DoD Standard 2167A, *Defense System Software Development*, and DoD Standard 2168, *Defense System Software Quality Program*. The following excerpt from the IFCS statement of work describes the overall mission critical computer resources (MCCR) development strategy:

> The MCCR requirements in this paragraph and subparagraphs apply to all FCS software and all support software/tools. The contractor shall develop all software (in accordance with) DoD Standard 2167 and DoD Standard 2168 from a total life cycle software support perspective. The development approach shall promote standardization of computer hardware and software with the objective of minimizing the number and types of computer hardware and languages to be utilized. [Ref. 21, p. 10]

In the following subsections, the IFCS software development program will be described by addressing several of the unique MCCR requirements within the IFCS contract's statement of work. The primary references for this section are the IFCS statement of work (reference 21), and the SDP prepared by LVS (reference 22).

a. Software Development Plan (SDP)

In response to a requirement in paragraph 3.2.4.1.1 in the IFCS statement of work, LVS has prepared and forwarded the IFCS SDP to the MLRS Project Office. The following excerpt from the SDP provides a general overview of the SDP:

> This plan describes the computer program development, test, and evaluation philosophy; establishes the basic design and coding conventions; sets forth the quality assurance and configuration management methods; and establishes the management structure and organizational responsibility for the software development effort of all CSCIs that are comprised with FCS. This SDP has been prepared in accordance with DOD-STD-2167. [Ref. 22, p. 5]

The following highlights of the SDP will be addressed below: software development activities; risk management; IV&V interface; software development library; and the helix software engineering process.

(1) Software Development Activities. The IFCS software development activities follow the recommended procession described in DoD Standard 2167. The IFCS SDP describes the software development activities as follows:

> FCS software development activities will consist of requirements analysis, preliminary design, detail design, coding, computer software unit (CSU) testing, computer software component (CSC) integration and testing, CSCI testing, and system test support. Each CSCI will be managed individually and have its own schedule. CSCIs to be developed by subcontractors will be managed by the Tactical Hardware Team via the Integration Team, as defined in the SEMP.
>
> Object-oriented (OO) methodology and the “Helix” software development cycle will be used for the development of CSCIs covered by this plan. Design, code, and test occurs at multiple points in the development process and at different levels of abstraction. Each band of the “Helix” provides for the accomplishment of a formal review (software specification review (SSR), preliminary design review (PDR), critical design review (CDR), and formal qualification test (FQT)). The schedules associated with each CSCI will be determined for each “Helix” band and will be provided in the software team schedule and hardware team schedule included at appendix. Schedule risk is indicated by critical path notation for each scheduled task. No schedule risk has been identified for software. [Ref. 22, p. 12]

(2) Risk Management. The software development risks identified in the SDP are as follows: Ada compilation system for the i960MX processor; timely availability of the developmental software support environment (DSSE); hardware stability; and schedule risk.

The SDP states that there is very little design and programming experience for the MX architecture microprocessors using the first generation compilation systems that are commercially available. This introduces risks associated with compiler selection, compiler availability, compiler quality, compiler capacity, code expansion ratios, and runtime characteristics. This risk has since been significantly reduced based on the selection of the i486 as the target processor. [Ref. 22, p.15]

The statement of work directs that LVS use the RATIONAL 1000 software development environment. This system has been procured for the contractor and provided as government furnished equipment (GFE) under the terms of the contract. Late delivery of the DSSE delayed critical training on the development system and risked further delays in project development. The DSSE was delivered two months late to LVS, but this slip was recovered prior to SSR. [Refs. 20, 22, p. 14]

According to the SDP, the IFCS LRUs and circuit card assemblies represent new hardware product development using state of the art technology. Because of the complexity of the hardware solution, the first generations imply risk. The development team's approach in mitigating this risk is to continue its involvement and support of the electronics vendor. [Ref. 22, p. 15]

The SDP states that the software schedule has been compressed and depends on the timely delivery of critical reusable components from the subcontractors. The schedule between SDR, SSR, and PDR is less than optimal as predicted by the Revised Intermediate Constructive Cost Model (COCOMO) software cost model. The software development team's mitigation strategy for this risk is to take steps necessary to optimize the advantages of the object-oriented approach within the "Helix" life cycle. [Ref. 22, p. 15]

(3) IV&V Interface. The IV&V contractor for the IFCS is a Government organization, MTD, a subordinate of the US Army Test and Evaluation Command (TECOM), located at White Sands Missile Range, New Mexico. MTD has over ten years of IV&V experience on the MLRS software including the original FCS, the version 6.0 FCS software, and the FDDM. The SDP states the developer's policy in dealing with the IV&V contractor:

> Access to the prime contractor facilities and data will be made available to all duly authorized IV&V agents so designated by the customer. Every effort will be made to ensure non-interference with development activities in order to preserve schedule and not disrupt the normal flow of development activities. IV&V activity will be coordinated through the Software Product Evaluation Manager. In all cases, the IV&V agent will be assumed to be acting on the part of the customer and accorded the same level of cooperation that would be provided to the customer.
>
> The philosophy of the prime contractor relative to interfacing with IV&V agents is to provide an atmosphere of cooperation aimed at two primary goals. These goals are product improvement and issue closure. Actions will be initiated as a result of IV&V results when it is determined by the prime contractor and the customer that a reported item demonstrates a non-conformance to process, product requirements, or represents a problem significant enough to warrant a change to requirements or processes which have been previously established. Prior to the initiation of any action, the closure criteria for satisfying the discrepancy must be agreed upon by both the prime contractor and the customer. [Ref. 22, p. 15]

(4) Software Development Library. The statement of work directs that the contractor establish a software development library for the control and management of all pertinent software code, test results, and documentation. This is one of the reasons that the IFCS PM included the provision for use of a GFE software development environment (the RATIONAL 1000 system). The RATIONAL 1000 generates and manages a software development library as part of the development environment. [Ref. 20] The SDP addresses the software development library as follows:

The RATIONAL configuration management and version control system (CMVC) combined with the RATIONAL subsystems will allow designers, developers, and project managers the ability to effectively and efficiently manage multiple generations of software development deliverables. These deliverables include design, program source, documentation, tests, and other project-related information. Deliverables make the transition through the design, development, test, and release stages in a controllable manner. [Ref. 22, p. 17]

(6) Helix Software Engineering Process. LVS is using a modification of the spiral model of software engineering. [Ref. 23] The process used, called the Helix software engineering process, follows the same type of cyclic development strategy used in the spiral model, except that each arc on the spiral is completed during a formal review or test. [Ref. 20] The SDP describes the Helix process as follows:

Software development within the Helix model is the engineering process that will be employed in the creation of FCS software. In contrast to implementing systems from the top down or bottom up, the iterative process, as represented in the Helix model, first constructs a system architectural prototype that performs minimal product functionality. System capability is then added incrementally through a series of iterations. In each iteration, a subset of the external system requirements is analyzed, designed, implemented, integrated, and tested. In this manner, the system evolves through a sequence of executable deliverables. [Ref. 22, p. 25]

b. Development Language

Ada (MIL-STD-1815) is the required implementation language for all FCS operational software, any contractor-developed software necessary to translate the operational software from the development environment to the tactical environment, and all test or tool software developed by the contractor which is used for acceptance testing or formal qualification. A Government-approved Ada waiver is required for all software that is not implemented in Ada. All Ada software delivered to the Government must be compiled on a compiler validated by the Ada Joint Project Office (AJPO). A graphical or textural Ada design language may be used, provided the design language is fully described in the SDP. [Ref. 21, p. 11a]

c. *Software Development Environment*

The Government has furnished LVS with a RATIONAL R1000 software development environment as Government furnished equipment (GFE) at a cost to the Government of approximately $1.2 million. According to Mr. Frank Gregory, chief of the MLRS software engineering branch, the reasons for providing the software development environment as GFE were as follows:

> We looked at what LVS had available to do the development - a (Digital Equipment Corporation) VAX network - and what they would charge us (the Government) for use of the network. Buying the RATIONAL system and providing it to LVS as GFE was less expensive in the long run. Also, the RATIONAL system is a better choice for meeting the specific configuration management needs of a large software development effort. It is better tailored to providing us with the reports and updates we need to oversee the development. [Ref. 20]

The SDP prepared by LVS addresses the projected training requirements for use of the RATIONAL 1000 environment. Up to 80 hours of training (conducted by Rational, Incorporated) are available for the IFCS software development team. [Ref. 22, p. B-2]

d. *Software Requirements Specification (SRS)*

The systems engineering process allocates system functional requirements among discrete system components. The software specification review (SSR), conducted in early 1994, and the software PDR, concluded in December 1994, identified the IFCS CSCIs and allocated specific requirements to each of the CSCIs. A clear understanding of these functional requirements is a critical factor in the developer's design and coding of the CSCIs. Subsequent to these reviews, the software developer prepares software requirements specifications (SRS) for each CSCI. Government review of the SRS ensures that the developer understands these requirements. [Ref. 4, p. 5-6]

The IFCS statement of work directs the contractor to prepare the SRS for each CSCI and provide the SRS to the Government in an object-oriented format. The complete directions in the statement of work concerning SRS are given in the following:

> The contractor shall prepare an SRS...for each CSCI. The contractor shall provide the SRS in an object-oriented format for all tactical embedded software. The contractor shall describe and document the exact format used for an object-oriented SRS in the SDP...All Computer Aided Software Engineering (CASE) tool files/databases used in the requirements analyses for the SRS shall be delivered in the appropriate format and available to the Government during review of the SRS. [Ref. 21, p. 11a]

e. MCCR Engineering Reviews, Tests, and Audits

Technical reviews, tests, and audits are scheduled by the contractor according to the timelines proposed in the SDP. [Ref. 4, p. 8-7] The IFCS statement of work provides the following directions concerning the conduct of reviews, tests, and audits:

> The major milestones associated with MCCR development shall concentrate on configuration identification, management and control, technical reviews, tests, and audits to be held at the contractor's site. These reviews, tests, and audits shall be conducted in accordance with MIL-STD-1521, at times to be delineated in the SDP, to analyze and control the development of the configuration items (CIs) and CSCIs.
> [Ref. 21, p. 12]

f. Non-developmental Software

In some circumstances, the IFCS developer may have access to software that has already been developed, tested, and used elsewhere. This software is classified as a non-developmental item (NDI), and may save the Government costs associated with a duplicate development effort. The IFCS statement of work permits the contractor to use NDI software, but requires the same documentation and testing as is required for developmental software. The following extract from the statement of work establishes this policy:

> Non-Developmental Items include "commercial off the shelf" (COTS) software, items previously developed by the contractor, items fielded by other US military services or Governmental agencies, or items fielded by US allies. Any NDI software (except COTS) shall be documented and tested in the same manner and to the same extent as required for software developed in accordance with this statement of work. [Ref. 21, p. 12]

g. Software Reuse Program

Significant development costs can be saved when a developer designs software for future reuse. One method of achieving this is to design certain software components around a "domain", or common architecture, that lends itself to ease of modification for future applications. The IFCS statement of work directs that the contractor establish a software reuse program, and directs its efforts (initially) at designing a domain for the weapon systems managers. The IFCS statement of work establishes this requirement as follows:

> The contractor shall initiate a software reuse program and describe the program in the SDP... Additionally, the contractor shall, as a part of the FCS effort, conduct a domain analysis. The domain analysis shall focus on determining the primitive capabilities that the MLRS FCS should supply to present and future weapon systems managers which will be hosted on the MLRS. The domain analysis shall include sources of commercially and freely available reusable components which have been considered by the contractor, and the results of the evaluation of these components... This domain analysis shall produce a set of components which supply these capabilities and a domain architecture for weapons systems managers which uses these components. Additionally, the contractor shall investigate and select one primary with two alternate sets of automated tools which can help to generate new weapons system managers from a user-supplied skeleton and the components from the domain analysis. After Government approval, this selected tool shall be built by the contractor as a part of the deliverables for this system. Finally, the contractor shall then use the tool to create three weapons systems managers as a proof of principle that the domain analysis was successful. The first two weapons systems managers shall be for the M77 rocket and the ATACMS missile. The third weapon

> systems manager shall be for a future missile which shall exercise the remaining capabilities present in the set of components created by the domain analysis. As part of the effort of creating the three weapons systems managers, the contractor shall collect additional metrics on the amount of reuse achieved in each of the weapons systems managers development and shall report these metrics as a part of the development deliverables. [Ref. 21, p. 12]

2. Acquisition Strategy and Contractual Features

During the process of selecting a developer for the IFCS, the MLRS PM sought a developer who, among other capabilities, was both familiar with the existing MLRS FCS and would be technically capable of developing the IFCS software using an object-oriented software development approach. In order to support the development of reusable software components, the object-oriented software development capability was considered by the PM to be "highly desirable". [Ref. 20]

The acquisition strategy for the IFCS features the sole-source award of a CPAF EMD contract to LVS in Dallas, Texas. This contract will be followed by a directed competition for the production and fielding of the IFCS. The justification for the sole-source development strategy is based on the contractor's experience (ten years) with the MLRS launcher, and the contractor's willingness to proceed with a focus on object-oriented software development. An industry survey confirmed that LVS was the most experienced developer for the IFCS. [Ref. 20]

The software development incentive feature of the contract includes an emphasis on software reuse. According to Mr. Frank Gregory, the incentive for successful implementation of the reuse provisions in the contract (as stated above in the statement of work) provides an award fee of one percent (up to a maximum of $1 million) of the total development cost. Distribution of the award fee is based on the subjective interpretation of the level of software reuse actually achieved as determined by a Government panel. The statement of work specifies software reuse metrics be reported to the Government at each major review. [Ref. 20]

3. Post Deployment Software Support (PDSS)

Upon acceptance by the Government, the IFCS software ultimately will be transitioned to its corresponding Government life cycle software support center: the US Army Missile Command's Software Engineering Directorate, located at Redstone Arsenal, Alabama. [Ref. 20] The statement of work includes two PDSS requirements: specifications concerning the life cycle software support environment, and a supportability demonstration. Both of these requirements are described below.

a. Life Cycle Software Support Environment (LCSSE)

The life cycle software support environment requirements are specified in the IFCS statement of work as follows:

> The LCSSE shall serve as the sole means of sustainment for the FCS software and shall include all commercial, Government funded, and contractor proprietary software, all documentation/specifications, plus executing hardware with all applicable licenses necessary to enable the Government to fully support all FCS software. [Ref. 21, p. 14]

b. Supportability Demonstration

The IFCS PM has specified that the contractor will demonstrate the LCSSE capability prior to final Government acceptance. The IFCS statement of work requires that the contractor "...conduct a LCSSE supportability demonstration at the contractor facility...to demonstrate that the LCSSE and documentation are adequate to support the FCS software." [Ref. 21, p. 14]

4. Software Testing

Software testing consists of both contractor-conducted and Government-supervised tests. Formal qualification tests are necessary prior to Government acceptance of a CSCI. [Ref. 4, p. 11-3] The IFCS statement of work addresses software testing in three areas: software test documentation, growth capability demonstration, and the software test readiness review (TRR). The overall software testing strategy is defined in the following extract from the statement of work:

> The contractor shall develop and conduct a logical progression of independent software testing in accordance with DoD Standard 2167. The Government may witness this testing at its discretion. The software testing program shall verify the performance, configuration, and reliability of all CSCI developed as a part of this contract. Software testing shall be initiated during requirements analysis, progress through software unit testing and software integration testing, and culminate in a formal software qualification test for each CSCI. The contractor shall record results of each informal and formal test performed in the software development files. This material shall be recorded in accordance with the SDP and shall include sufficient documentation such that all testing contained in them is reproducible and verifiable, and demonstrates that all software paths have been traversed at some level of testing. [Ref. 21, p. 37]

a. Software Test Documentation

The IFCS statement of work requires the contractor to prepare software test plans (STPs), software test reports (STRs), and software test descriptions (STDs). Government approval of the STP is required prior to the PDR. Government approval of the STD is required prior to completion of the software TRR. [Ref. 21, p. 37]

b. Growth Capability Demonstration

The IFCS statement of work directs the contractor to perform a growth capability demonstration prior to the completion of the formal qualification testing (FQT). The following excerpt from the IFCS statement of work addresses the growth capability demonstration:

> One operational system shall be demonstrated by the end of the formal qualification test (FQT) milestone that incorporates the memory and throughput growth requirements of the system specification. This requirement may be satisfied using prototype hardware in a laboratory environment. [Ref. 21, p. 37]

c. Software Test Readiness Review

The IFCS statement of work addresses test readiness reviews as follows:

> The contractor shall conduct a TRR for each CSCI in accordance with MIL-STD-1521 and DOD-STD-2167. Test readiness reviews shall be scheduled at least thirty days in advance and shall be conducted at the contractor facility. [Ref. 21, p. 37]

5. Software Quality Assurance

Software quality is addressed in four paragraphs in the IFCS statement of work. The following subsection will discuss the IFCS software quality program, software metrics, software quality factors, and software complexity.

a. Software Quality Program

The IFCS statement of work requires that the contractor implement a software quality program in accordance with the provisions of DoD Standard 2168. The plan will apply to all software developed under the contract, including any test or diagnostic software used during development. The plan will include the procedures used to perform the evaluations described in DoD Standard 2167 (Figures 4-10).
[Ref. 21, p. 43]

b. Software Metrics

The IFCS statement of work addresses software metrics as follows:

> The contractor's software quality assurance organization shall ensure the implementation and maintenance of a software metrics program with the guidance of Department of the Army Pamphlet 73-XX (Army Software Test and Evaluation Panel (STEP) Metrics), Chapter 17. The 12 metrics are as follows: Cost, Schedule, Computer Resource Utilization, Software Engineering Environment Requirements Traceability, Requirements Stability, Design Stability, Complexity, Breadth of Test, Depth of Test, Fault Profiles, and Reliability. The contractor shall present analysis/interpretation of the data collected at all design and in-process reviews. [Ref. 21, p. 43]

c. *Software Quality Factors*

The IFCS statement of work defines software quality factors in the following:

> The contractor's software requirements specifications shall address the software quality factors of maintainability, interoperability, and complexity. The contractor shall propose a quantifiable methodology for measuring the maintainability and interoperability of the mission critical software developed. [Ref. 21, p. 43]

d. *Software Complexity*

Software complexity, as a measure of software quality, is defined by the IFCS statement of work in the following:

> For each unit of mission critical software, the cyclomatic complexity of ninety percent of the program units shall not exceed the following levels defined by the National Bureau of Standards Special Publication 500-99. Units proposed to exceed the following levels require approval by the Government prior to finalization of the unit design.
>
> | | |
> |---|---|
> | Program design language | 7 |
> | Code | 10 |
> | Redesigned code due to software errors | 12 |
>
> When calculating the complexity metric for each unit when "case" statements are used, add a complexity count of 1 for the "case" statement and add the complexity count for the most complex path embedded in the "case" statement.

This section described the IFCS software development strategy. The discussion included the following: the software development program, the software acquisition strategy and contractual features, the post deployment software support (PDSS) plan, the software testing requirements, and the software quality program. The section that follows will summarize the chapter.

D. SUMMARY

The improved fire control system (IFCS) constitutes a significant upgrade to the existing FCS capabilities of the MLRS launcher. The improvements include: an enhanced digital communications capability, expanded fire control automation, improved system flexibility, improved and expanded user interface, and reduced operations and support costs. These improvements will effectively modernize the MLRS launcher and prepare it for operations on the evolving digital battlefield to support the Army's Force XXI vision.

The IFCS software development strategy is following an object-oriented approach. The contractor has implemented several innovative methods to software development, including a Helix software engineering process that will evolve the requirements into functional software through successive process iterations. All program testing and reporting is being conducted in accordance with DoD Standard 2167 and DoD Standard 1521.

This chapter provided a detailed description of the IFCS program including the system acquisition strategy and schedule, described the IFCS and its major hardware and software components, and described the IFCS software development strategy. The next chapter summarizes the lessons learned from the FDDM, and compares the FDDM and IFCS software development strategies.

V. ANALYSIS AND APPLICATION OF FDDM LESSONS LEARNED

The purpose of this chapter is to analyze the lessons learned from the FDDM software development effort and apply these lessons to the IFCS development effort. This chapter is organized as follows: first, the FDDM lessons learned are summarized; secondly, the FDDM and IFCS development programs are compared using the same format as the FDDM lessons learned; and lastly, the FDDM lessons learned and specific IFCS applications of the lessons learned are summarized.

A. FDDM LESSONS LEARNED

In reviewing the FDDM case study, a number of acquisition lessons learned may be apparent. The focus of this thesis, however, is analysis of the software development lessons that can be derived from the FDDM case study. In an effort to determine the proximate causes of the FDDM software development challenges, the FDDM case study will be analyzed in the following areas: functional requirements, program management structure, software development strategy, choice of contractual mechanisms, and choice of development contractor.

1. Functional Requirements

System functional requirements evolve from the mission need statement (MNS) and operational requirements documents (ORD). Since the FDDM was not originally intended as a fieldable system, but as a test device for the ATACMS OT, these documents were not required. Likewise, since the original hardware design proposed for the FDDM consisted of NDI hardware (GFE), a system specification ("A" specification) was not prepared. The combination of these factors early in the program distorted the traditional systems engineering framework within which system requirements are normally developed. It is for this reason that this analysis begins with the FDDM system requirements.

In 1987, when the FDDM concept changed from that of a test device (supporting the ATACMS OT only), to a fieldable system (in support of the entire MLRS family of munitions - MFOM), the existing FDDM requirements and program should have been re-baselined. Continuing the program structure in its original context led to an incremental "evolution" of requirements. Ultimately, the FDDM requirement became that of a C^3I system, which was inconsistent with the existing program management structure, software development strategy, choice of contractual mechanisms, and choice of development contractor.

The software management lesson learned is: *if the combination of requirements changes constitute a change in scope, the program must be re-baselined.* In the sections that follow, the effects of this scope change will be repeated in subsequent lessons learned.

2. Program Management Structure

The original FDDM program management structure was nonexistent. Managed as a test device using GFE hardware, the FDDM development was relegated to that of a contractual deliverable only. Following the change in FDDM scope, the FDDM management structure was established and elevated to that of a product manager (the MFOMC^3I product manager) within the MLRS PM office.

The policy question at issue is whether or not the MLRS PM office - an organization that is chartered to design and build rocket/missile launchers, munitions, and associated support equipment - was the appropriate management structure to develop a C^3I system. The Army's expertise in building C^3I systems lies within the Program Executive Office, Command and Control Systems. This is the same organization that is (and was at the time) managing the development of the AFATDS - for which the FDDM was considered an interim system.

The software management lesson learned is: *the program management structure should be consistent with the type of system being developed.* When the FDDM concept changed to a fieldable C^3I system, management should have transferred to the AFATDS

PM within the PEO for Command and Control Systems. In addition to being managed by the Army's C^3I experts, the FDDM would have been better positioned for eventual integration into the AFATDS functionality.

This lesson learned could be extended further, in light of the increasing role of software in weapon system acquisition. As weapon systems become more software-dependent, there is an increasing role for software management professionals on the PM staff. The MLRS PM office has established a software engineering branch within its technical management division. These software professionals assist the PM in developing software management plans and providing contract oversight. [Ref. 20] In software-intensive development efforts, again, the program management structure should provide for this expertise.

3. Software Development Strategy

Analysis of the FDDM software development strategy provides us with three lessons learned. These lessons are:

- *modular program design increases software flexibility;*
- *the use of Ada leads to a disciplined, modular approach that more readily accommodates future changes;* and,
- *a software development effort cannot proceed without a validated software development plan (SDP) and software test plan (STP).*

Each of these is discussed below.

When the system requirements underwent significant change, the original modularity of the FDDM design was instrumental in reconfiguring the software to accommodate the changes. The design of the weapon SPAPs, for example, required little modification when the host computer changed from the BCU to the TCU, and ultimately to the LCU, prior to fielding. Likewise, initial FDDM functionality was achieved during the December 1991 ISIT, despite the incompleteness of the database management software. The modularity of the FDDM software allowed testing of some program components while others proceeded in design and development.

The use of Ada proved essential to the program's completion after the FDDM development was transferred from the original prime contractor to Telos in August 1991. Upon receipt of the incomplete FDDM software, Telos was able to achieve the desired initial FDDM functionality in six months (by December 1991). The Ada standard is universally understandable by Ada-qualified developers. The Ada source code itself is also readily understood. Additionally, the use of Ada forces the generation of reports and documentation that clearly defines each piece of software developed. This structured approach greatly enhanced software trouble-shooting during testing. [Ref. 11]

According to the Defense Systems Management College's, *Mission Critical Computer Resources Management Guide,* "...the SDP and the STP are the basic documents governing the conduct of the mission critical computer resources development and test activities." [Ref. 4, p. 6-2] The SDP, developed by the original prime contractor, was insufficient and did not adequately address software testing. [Ref. 2, p. 8] When the prime contractor was unable to discover software errors during testing, it was likely that errors would surface during customer demonstrations (e.g., the December 1989 C^3I demonstration at Fort Sill).

4. Choice of Contractual Mechanisms

The FDDM was originally intended to be developed under a firm-fixed-price contract. As changes to the contract amounted to a change in contract scope, the contract was amended to include the additions, but remained a fixed-price contract. Subsequently, the Government was required to pay incrementally more for each contract change.

The original FDDM prime contractor stood to recognize a profit on this contract only by restricting the overall level of effort within each incrementally negotiated contract price. Because this contractor was operating in a bankrupt status at the time, resources were unavailable to hire the required software professionals for the FDDM effort. As a result, the available software staff did not possess the software engineering capability and experience to develop a software-intensive C^3I system. Additionally, any software process "learning" would have occurred at a loss to this contractor. [Refs. 8, 10, and 16] For this reason, there was no incentive for the contractor to invest in the costs of applying modern software management techniques that would only add to growing losses on the FDDM effort.

According to the *Government Contract Guidebook*, acquisitions involving a considerable amount of risk should employ a contract designed to share the risk equitably between the Government and the developer. Generally, cost-type contracts are recommended for risk-intensive development programs. Modifications to cost-type contracts can incentivize specific performance attributes such as cost, timeliness, and quality. [Ref. 24, p. 2-19]

Software development programs are inherently risk-intensive, and the FDDM development effort was not an exception to this general rule. When the sum of the FDDM requirements changes amounted to a change in scope, the original, fixed-price contract was no longer the appropriate contractual mechanism upon which to proceed. The software management lesson learned is: *software development efforts should be contracted under a cost-type contract that balances the risk between the Government and the developer, and allows for desired incentive provisions.*

5. Choice of Development Contractor

The original FDDM prime contractor was chosen for the degree of experience acquired while working on the MLRS launcher. This was reasonable, considering the minimal software design required in the original FDDM concept, and the intent to use the existing MLRS FCS hardware. This justification was no longer relevant, however, when the requirement for the FDDM changed from its original purpose to that of a fieldable C^3I system. Additionally, the prime contractor's hardware expertise was no longer of value when the hardware design was changed from the existing BCU to the TCU.

As weapon system development programs become more software intensive, contractors should be selected for programs based on relevant, demonstrable software proficiency and domain (i.e., C^3I) experience. Assessment tools, such as the Software Engineering Institute's Software Capability Assessment, can assist acquisition executives in selecting contractors who demonstrate strong software management acumen within the application domain. A developer who was strong in the management of C^3I software programs would have been the appropriate choice in the case of the FDDM. The software development lesson learned is: *the development contractor's software management capability and domain experience should be commensurate with (and relevant to) the degree and type of software risk in the program.*

In summary, the FDDM software lessons learned are:

- if the combination of requirements changes constitute a change in scope, the program must be re-baselined;
- the program management structure should be consistent with the type of system being developed;
- modular program design increases software flexibility;
- the use of Ada leads to a disciplined, modular approach that more readily accommodates future changes;
- a software development effort cannot proceed without a validated software development plan (SDP) and software test plan (STP);
- software development efforts should be contracted under a cost-type contract that balances the risk between the Government and the developer, and allows for desired incentive provisions; and,
- the development contractor's software management capability and domain experience should be commensurate with (and relevant to) the degree and type of software risk in the program.

In the section that follows the FDDM and IFCS software development program similarities and differences will be determined.

B. COMPARISON OF THE FDDM AND IFCS DEVELOPMENT PROGRAMS

No two development programs, when compared, will be identical. However, in analyzing different programs (with similar functions or capabilities) several common attributes are often apparent. For the purpose of this discussion, the relevant program attributes are requirements and risks. All development programs are initiated with a requirement, which, when validated, incurs development risks. For example, all acquisition programs are constrained by the general risk categories of cost, schedule, and performance. It is the chartered responsibility of the program manager to develop a programmatic solution to the requirement, while managing the risk level of each of these categories against the others.

When analyzing a program's functional requirements, additional similarities and differences emerge. In the FDDM and IFCS programs, functional requirements drove the developer to propose a solution that combined the use of both hardware and software components. While the focus of this thesis has been the software requirements, the relationship between hardware requirements and software requirements, within the systems engineering process, is paramount. As discussed initially in the first chapter of this thesis, more frequently we are seeing requirements "pushed off" onto software that would be otherwise unattainable using a purely hardware-oriented solution.

This section provides a comparison of the similarities between the software development programs of the IFCS and the FDDM. The same analytic approach will be used for these comparisons as was used for deriving the FDDM lessons learned. For each general program management area, the FDDM lesson(s) learned will be summarized. Following this, the IFCS software development program will be analyzed in the same general area to determine the relevance or applicability of the FDDM lessons learned. As was done for the FDDM lessons learned, this analysis will be performed in the following areas: functional requirements, program management structure, software development strategy, choice of contractual mechanisms, and choice of development contractor.

1. Functional Requirements

a. FDDM Lesson Learned

The FDDM functional requirements lesson learned is: *if the combination of requirements changes constitute a change in scope, the program must be re-baselined.*

b. IFCS

The requirement for the IFCS originated within the MLRS project office. The existing FCS design is nearly 15 years old and outdated. Plans to upgrade the design have been studied throughout the MLRS life cycle. For this reason, the IFCS program has proceeded immediately into its EMD phase.

To meet the future C^3I requirements imposed by evolving weapon systems and national fire direction centers, the current FCS must be upgraded in terms of speed, capacity, and flexibility. Additionally, the emerging requirements of the Army's battlefield digitization effort dictate the modernization of the MLRS platform as a digital system. Lastly, the defense drawdown's effect on the military industrial base has made it desirable that the MLRS FCS be modernized (to the extent possible) using common (versus military-specific) hardware.

There are two functional requirement risks incurred by the IFCS software development program. First, the IFCS incurs the risk of potential changes in functional requirements as the Army's data architecture for battlefield digitization becomes finalized. Secondly, the IFCS functional requirements have the potential to "snowball" in an effort to extend IFCS functionality to include full battlefield digitization. The first of these risks has the potential of making the IFCS obsolete or incompatible with the Army data architecture if requirements are not changed. The second risk could extend the development timeframe well beyond current projections in an effort to accommodate evolving requirements.

In mitigation of these risks, the IFCS requirements, as presently defined, stress maximum flexibility and the ability for future growth to accommodate increased digital information interchange on future digitized battlefields. This has necessitated an "open" hardware architecture which makes use of commercially available standard components and interfaces. The software is required to remain adaptable to these potential hardware changes.

An object-oriented approach (as opposed to an approach based on function/data systems) can mitigate potential requirements changes if the approach is implemented correctly. The following excerpt from *Object-Oriented Software Engineering*, by Ivar Jacobson, illustrates this point:

> This is yet another reason that function/data systems become more difficult to modify. Owing to the fact that they are designed around how a certain behavior will be carried out (this being a common area of modification), modifications often generate major consequences. Object-oriented methods structure the system from the items which exist in the problem domain. This is often a more natural way to describe the system. These items are normally very stable and change very little. The changes which do occur normally affect only one or a few such items, which means that the changes made are usually local in the system. If we wish to have a stable system, we should consider what has a tendency to change, and then design according to this knowledge. [Ref. 25, p. 75]

As discussed in the previous chapter, the IFCS statement of work requires that LVS employ an object-oriented approach. The SRS for each CSCI is required to be delivered to the Government in an "...object-oriented format." [Ref. 21, p. 11a] If this approach is followed from requirements determination through coding, the impact of hardware requirements changes on software requirements could be mitigated. However, this is not apparent in the IFCS statement of work. It appears that the goal of the IFCS object-oriented approach is to achieve a desired level of software reusability, specifically in the weapons management software, and not mitigation of hardware-based requirements risks. If significant hardware and software requirements changes result from the Army's digitization effort (e.g., data architecture standards) the IFCS software may require significant modifications.

2. Program Management Structure

a. FDDM

The FDDM program management structure lesson learned is: *the program management structure should be consistent with the type of system being developed.*

b. IFCS

The current IFCS program management structure is consistent with the development of an improved MLRS FCS. The primary requirement for the IFCS is modernization of the existing FCS. However, to accommodate future C^3I digitization requirements, the IFCS solution is software-intensive and includes a highly flexible, "open" design. Potentially, the IFCS requirements could drive the development effort to mandate C^3I expertise that lies outside the existing management structure.

As the Army's digitization effort matures, the IFCS program requirements may evolve into those of a more complex C^3I system. This is similar to the growth in requirements (and change in scope) experienced during the FDDM development. In mitigation of this potential risk, the IFCS PM must exercise requirements discipline sufficient to maintain the current focus of the program as a fire control system for the MLRS. If requirements changes begin to dictate otherwise, coordinating efforts with more experienced C^3I system developers (e.g., the CECOM Software Engineering Center) should be considered.

3. Software Development Strategies

a. FDDM

The FDDM software development strategy lessons learned are: *modular program design increases software flexibility; the use of Ada leads to a disciplined, modular approach that more readily accommodates future changes;* and, *a software development effort cannot proceed without a validated software development plan (SDP) and software test plan (STP).*

b. IFCS

The IFCS software development strategy incorporates several of the "modern" software management techniques that have evolved as a result of past DoD software development difficulties. In light of the FDDM lessons learned, the IFCS development strategy includes the following: an object-oriented approach (which leads to a modular, reusable design); required use of the Ada programming language to enforce a structured, disciplined development approach; and an approved software development plan and software test plan.

4. Choice of Contractual Mechanisms

a. FDDM

The FDDM contractual mechanisms lesson learned is: *software development efforts should be contracted under a cost-type contract that shares risk between the Government and the developer equally, and allows for desired incentive provisions.*

b. IFCS

The IFCS contract is a cost plus award fee (CPAF) contract with software development incentive provisions for the extent of software reuse achieved in the development. This type of contract distributes development risk equitably between the contractor and the Government. Additionally, the incentive provision (award fee) emphasizes the Government's desire for a software reuse library that will reduce future costs associated with maintaining the software.

5. Choice of Development Contractor

a. FDDM

The FDDM lesson learned in the choice of a development contractor is: *the development contractor's software management capability and domain experience should* *be commensurate with (and relevant to) the degree and type of software risk in the program.*

b. IFCS

The IFCS development contractor is LVS Corporation, whose corporate headquarters is in Dallas, Texas. The IFCS software development is being conducted at LVS facilities located in Grand Prairie, Texas. [Ref. 22, p. 9] The LVS Corporation is the successor (as the result of a corporate merger) to the same prime contractor that was originally contracted to design and build the FDDM. Several of the software development personnel working on the IFCS program team were formerly assigned to the FDDM development team. [Ref. 20]

LVS was chosen for the IFCS development effort principally for their experience with the original MLRS FCS. However, because of the software-intensive nature of the IFCS development, the *current* software management capability of LVS was a factor of consideration during contractor selection. While an independent software capability assessment was not performed to determine the capabilities of LVS, the software management concerns of the MLRS PM are addressed throughout the IFCS system specification and statement of work (references 19 and 21). The software engineering branch of the technical management division has worked closely with the IFCS PM in designing the requirements for the system specification and statement of work to reflect the Government's desire to maintain a structured, disciplined software development effort. Examples of this include the following:

- Language requirements, code requirements (including use of "patches"), memory reserve, processing speed/throughput, and throughput growth are addressed in paragraph 3.1.1.10 of the system specification. [Ref. 19]
- Use of DoD Standards 2167 and 2168 dictating a "total life cycle software support perspective" is addressed in paragraph 3.2.4 of the statement of work. [Ref. 21]

- Use of Ada and Ada design language requirements, software source code documentation specifications, and the software development environment (the RATIONAL system) requirements, are specified in paragraph 3.2.4.1 of the statement of work. [Ref. 21]

According to Mr. Robert Wilks, IFCS product manager for the MLRS PM office, this method of risk mitigation is the result of having a dedicated team of software professionals within the MLRS organization. This resource (the software engineering branch) was not part of the MLRS PM structure when the FDDM program was initiated. [Ref. 9]

This section compared the FDDM and IFCS software development strategies to determine whether or not the FDDM software lessons learned were applicable. The IFCS software development strategy was summarized in the following areas: functional requirements; program management structure; software development strategy; choice of contractual mechanisms; and choice of development contractor. In each of the analyses, the risk areas were identified as well as those steps taken by the IFCS PM to mitigate those risks. The analyses presented in this chapter are summarized in the following section.

D. SUMMARY

The FDDM and IFCS programs are similar in several areas. First, both system design solutions proposed a combination of hardware and software. Second, both systems are required to meet a fire support C^3I requirement in addition to other requirements. Third, the programs share a similar program management structure, within the MLRS PM office, and as matrix-supported product management offices. Fourth, both programs mandated the use of Ada as a programming language, and pursued a modular software design and development approach. Lastly, the same prime contractor was selected to develop the system.

The primary differences between the FDDM and the IFCS efforts are the software engineering approach and the contractual mechanism. The FDDM followed an incremental software engineering approach that sought to accommodate increasing requirements through increased development. The IFCS is employing a structured and disciplined software engineering approach with emphasis on reuse. The FDDM was a fixed-price contract, where the IFCS is a cost plus award fee contract.

This chapter discussed the lessons learned from the FDDM software development effort and applied these lessons learned to the IFCS development effort. The following chapter will state the conclusions and recommendations of this thesis, answer the research questions proposed at the beginning of the thesis, and list areas for additional research.

VI. CONCLUSION

This thesis established the lessons learned from the FDDM software development effort. With these lessons learned, an analysis was presented of the IFCS software development strategy, identifying software risk areas and proposed methods to reduce or control these software risks in the IFCS development program. In this section, the thesis research questions are answered and recommendations are made for additional research.

A. ANSWERS TO RESEARCH QUESTIONS

This section provides summarized answers to the research questions presented in the introduction to this thesis.

1. Primary Research Question

The primary research question for this thesis is: **How was the software for the FDDM developed, and what lessons learned from that effort can be applied to the IFCS?**

- The FDDM software development strategy was strongly influenced by the changing requirements of the FDDM system.
- The original requirement for an FDDM (as a test device for the ATACMS OT) required very little software development. As a result, an initial detailed software development strategy was not prepared.
- Following the FDDM requirements change from a test device to a fieldable C^3I system, the FDDM software development effort was greatly expanded. The resulting development strategy, while significantly more involved than the original, did not follow the guidelines presented in DoD Standard 2167 or Military Standard 1521.
- The sum of requirements changes in the FDDM constituted a change in scope and mission for the FDDM. As a result, the original FDDM prime contractor

was incapable of meeting the requirements within the terms and conditions of the original contract.

- As a result of significant development difficulties encountered by the original FDDM prime contractor, the incomplete software development effort was turned over to a contractor with demonstrated proficiency in C^3I system development under the direction of the Fort Sill Center for Software Engineering.
- Using a rapid prototyping approach, the second FDDM software developer completed the FDDM software functionality and delivered an acceptable product to the Army.
- The lessons learned from the FDDM that can be applied to the IFCS development effort include the following:
    - *if the combination of requirements changes constitute a change in scope, the program must be re-baselined;*
    - *the program management structure should be consistent with the type of system being developed;*
    - *modular program design increases software flexibility;*
    - *the use of Ada leads to a disciplined, modular approach that more readily accommodates future changes;*
    - *a software development effort cannot proceed without a validated software development plan (SDP) and software test plan (STP);*
    - *high risk software developments should be contracted under a cost-type contract that shares risk between the Government and the developer equally, and allows for desired incentive provisions; and,*
    - *the development contractor's software management capability and domain experience should be commensurate with (and relevant to) the degree and type of software risk in the program.*

2. Supporting Research Questions

The supporting research questions for this thesis are as follows:

What difficulties were encountered in the FDDM development effort, and of these, were they foreseen as risk areas by the project manager?

- The principle difficulties encountered by the FDDM development effort were driven by expanded requirements to field the FDDM and support the additional munitions of the MFOM.
- When the requirement for the FDDM changed from a test device to a fieldable system, additional software development requirements were added including software documentation, maintainability, and safety.
- Several of the programs in the MFOM were special access programs ("black" programs) that greatly increased the complexity of interface requirements. The increased complexity and communications challenges inherent in these special access programs resulted in a substantial challenge to the FDDM software development process.
- The original FDDM prime contractor was not proficient in the development of software for C^3I systems and was unable to complete the FDDM development.
- The FDDM PM was not originally aware of the complexity of the special access programs in the MFOM and could not have foreseen the challenges of integrating these requirements. The decision to field the FDDM as a C^3I system constituted a significant change in the scope of the development effort. Questions should have been raised immediately following this decision as to the program baseline, program management structure, type of contract used, software development strategy, and choice of development contractor.

What effects did the choice of Ada, as a programming language, have on the complexity and level of difficulty in the software development effort for the FDDM? In what ways did requirement changes affect the software development of the FDDM?

- The selection of Ada as the programming language for the FDDM enforced discipline in the structuring and documentation of the code generated by the original prime contractor. As a result, the second FDDM software developer was able to assume responsibility for the development project quickly, and rapidly complete the coding. The choice of Ada was significant in the successful completion of the FDDM software.
- The FDDM software development effort grew significantly as the result of the requirements changes. As a result of the structured, disciplined nature of the Ada development environment, these requirements changes were more easily accommodated in the overall software development effort.
- The challenges of the FDDM software resulted from the change from a test device to a C^3I system (and the subsequent requirements changes), not the use of the programming language.

Was the primary contractor for the FDDM software development effort sufficiently qualified (mature) for that program?

- The original FDDM prime contractor was qualified to develop the FDDM as a test device for the ATACMS OT. This contractor had been selected based on experience with MLRS FCS components, not development of complex C^3I systems.
- When the FDDM requirement changed to a fieldable C^3I system, the prime contractor was at a loss for experience in that domain. Domain experience, as well as software process capability (or maturity), are equally important in the selection of a qualified software developer.

What type of contract was used for the development of the FDDM software, and what specific military standards, specifications, and metrics were called for in that contract? Was this the best type of contract for this design effort?

- A firm-fixed price contract was the mechanism used for the original FDDM development.
- Because the original FDDM was not be a fielded system, DoD Standards 2167 and 2168, and Military Standard 1521 were not applied in the contract.
- The original contract mechanism was sufficient for the level of risk in the proposed FDDM. When the FDDM requirements underwent significant changes, the original contract should have been renegotiated as a cost-type contract, or terminated for the convenience of the Government and re-competed under the new technical baseline.

What type of contract is being used to develop the IFCS software, and what specific military standards, specifications, and metrics will be called for in that document? Are there any shortcomings in this contract?

- The IFCS is being developed under the terms of a cost plus award fee (CPAF) contract. Contract incentive provisions include software reusability.
- Among other military standards and specification, the IFCS contract requires the development to proceed in accordance with DoD Standards 2167 and 2168, as well as Military Standard 1521.
- The analysis of the IFCS statement of work uncovered no shortcomings in the software development management of this contract. Risk areas in functional requirements, program management structure, and the software development strategy appear to be sufficiently mitigated through the use of incentives, Government oversight and review, and military standards and specifications.

What other software development efforts have been considered, or used as models, for the software engineering effort for the IFCS?

- The prime contractor for the IFCS is using a "Helix" software engineering model. This is similar to the spiral software development model. [Ref. 23]
- The "Helix" approach has been modified to accommodate the specific review and audit requirements of DoD Standards 2167 and 2168, and Military Standard 1521. Each spiral arc on the helix culminates in a mandated program review, as specified by the aforementioned standards.

Under DoD Standard 2167, what tailoring has been done, and how is the contractor implementing these modifications?

Tailoring requirements of DoD Standard 2167 are presented in the IFCS statement of work. The contractor has addressed these requirements in the SDP. Included in the tailoring requirements are the following:

- Ada and Ada design language are the required language for all IFCS software. However, a graphical or textural Ada design language may be used provided sufficient documentation and descriptions are provided in the contractor's SDP.
- The contractor is required to assemble an automated software development environment and make extensive use of commercially available software and hardware for the development environment. The Government has provided a RATIONAL 1000 development environment as GFE.
- The RATIONAL 1000 development environment provides modified Army STEP metrics (12 total) to the IFCS PM as required. The contractor is required to maintain and update the metrics database in the RATIONAL system.
- The contractor is required by the statement of work to provide the Government with an SRS for each CSCI in an object-oriented format.

Paragraph 8.1 of the SDP identifies a standard format for documentation of the SRS and the object-oriented approach that the contractor will follow.

- The IFCS statement of work mandates the establishment of a software reuse library. Initial requirements for the demonstration of software reusability include the development of reusable weapons system managers. Paragraph 8.3 of the SDP describes the reuse library and procedures that the contractor will follow.

B. RECOMMENDATIONS FOR FURTHER RESEARCH

The following areas are recommended for additional research:

1. Implementation of an Object-oriented Approach

The object-oriented methodology can enhance the reusability of software in DoD weapon systems. Additional research should be focused on the following: how DoD program managers could implement this approach, what the uses and benefits of this approach would be, the tailoring requirements for applicable military standards and specifications, and the contracting implications of an object-oriented approach.

2. Effects of Eliminating Military Standards and Specifications on Software Development Contracts

The current structure of DoD Standards 2167, 2168, 1521, and the recently approved Military Standard 498, present a familiar management framework within which DoD weapon system software is developed. Additionally, numerous military standards and specifications mitigate program technical risk by establishing readily available guidelines. The Defense Management Review Task Force has recommended greatly reducing (or eliminating entirely) many of these standards and specifications. The Army has taken this policy one step further by eliminating the use of *all* military standards and specifications except on an approved, exceptional basis. This invites additional research in the following areas: the sufficiency of industry standards to meet DoD-specific software requirements, the implications of industry standards in risk management, the development of performance requirements for the management of software, and the contractual implications of performance requirements in software development.

3. Software Engineering Professionals and the PM Staff

DoD weapon systems are increasingly software-reliant, but many PM staffs still consist of managers with a predominantly hardware-oriented background. Additionally, with greater competition from industry, Government PMs will have to work even harder to attract qualified software professionals. Additional areas for research include: the professional development, training, and promotion opportunities available for Government software professionals; the Government incentive structure for attracting and retaining software professionals; software training requirements for Government PMs; and the PM software engineering staff and its role in the systems engineering process.

4. Contract Incentive Provisions for Software Engineering Management

Software engineering is still a relative newcomer to the systems engineering process, and is evolving as an engineering discipline. While the IFCS contract makes a number of advances in unique software provisions, clearly there is much to be learned and explored in how the Government manages the software engineering processes of a development effort. Additional research would be beneficial in the following areas: selection of a contractor based on both domain expertise and software management capability; identification of risk attributes associated with an object-oriented approach; contractual implications for the use of artificial intelligence, virtual reality, and expert systems in the software development process; and analysis of current cost-, schedule-, and performance-based incentive features in software contracts.

C. CONCLUSIONS

This thesis addressed the nature of embedded software management as an increasingly critical area in DoD weapon system's project management. As the requirements for software-intensive systems grow, the application of modern software management principles will become more important in mitigating the cost-, schedule-, and performance-based risks of embedded software.

The FDDM case study is one of many DoD development programs that have encountered significant software challenges. The recent history of DoD software acquisition would indicate that there is much to be learned from studying both the successes and failures of previous development programs. By analyzing the results of previously employed software management techniques, acquisition managers can better prepare for the software risks in future programs. For example, the IFCS software development strategy exhibits a number of the lessons learned from the FDDM development effort.

The IFCS analysis in this thesis revealed several areas that may provide additional software risk mitigation techniques for DoD acquisition managers. The IFCS statement of work explicitly addresses several modern software development initiatives. These initiatives include: emphasis of an object-oriented design approach, specific provisions for the achievement of software reuse, and the specification of a Government-furnished software development environment (the RATIONAL 1000 system). These initiatives, while unique to the IFCS development, may provide invaluable experience to software professionals throughout the DoD.

As software engineering continues to evolve as a discipline, case studies and analyses of development programs (such as the FDDM and the IFCS) will continue to refine the software acquisition strategies and techniques available to DoD project managers. In an era of simultaneously declining Defense resources and increasing requirements complexity, the value of these strategies and techniques will be magnified in importance.

APPENDIX A. LIST OF ACRONYMS

AFATDS	Advanced Field Artillery Tactical Data System
AGSM	Army Ground Station Module
AJPO	Ada Joint Program Office
ARTEP	Army Training and Evaluation Program
ASAS	All Source Analysis System
ASIOE	Associated Support Items of Equipment
ATCCS	Army Tactical Command and Control System
BAT	Brilliant Antiarmor Submunition
BCD	Brigade-Corps-Division
BCU	Battery Computer Unit
BII	Basic Issue Item
BIT	Built In Test
BOC	Battery Operations Center
C^2	Command and Control
C^3	Command, Control, and Communications
C^3I	Command, Control, Communications, and Intelligence
CA	Common Application
CASE	Computer Aided Software Engineering
CCA	Circuit Card Assembly
CDR	Critical Design Review
CECOM	Communications and Electronics Command
CCS	Command and Control System
CDPU	Communications and Data Processing Unit
CDU	Communications Distribution Unit
CF	Configuration
CHS	Common Hardware and Software
CMP	Communications Processor
COCOMO	Constructive Cost Model
COMSEC	Communications Security
COR	Contracting Officers Representative
COTS	Commercial Off The Shelf
CPAF	Cost Plus Award Fee
CSC	Computer Software Component
CSCI	Computer Software Configuration Item
CSU	Computer Software Unit
CTOCSE	Corps Tactical Operations Center Support Element
CTS	Contact Test Set
CTT-H	Commanders Tactical Terminal-Hybrid

DA	Department of the Army
DCSOPS	Deputy Chief of Staff, Operations
DMA	Defense Mapping Agency
DoD	Department of Defense
DPICM	Dual Purpose Improved Conventional Munition
DPU	Data Processing Unit
DRAM	Dynamic Random Access Memory
DS	Direct Support
DSSE	Development Software Support Environment
DSU	Direct Support Unit
DTED	Digital Terrain Elevation Data
ECP	Engineering Change Proposal
EDT	Engineering Development Test
EMD	Engineering and Manufacturing Development
FA	Field Artillery
FC	Field Circular
FCS	Fire Control System
FDAE	Fire Direction Adaptation Equipment
FDC	Fire Direction Center
FDDM	Fire Direction Data Manager
FCP	Fire Control Panel
FCS	Fire Control System
FDS	Fire Direction System
FDTE	Force Development Test and Experimentation
FH	Frequency Hopping
FM	Frequency Modulation
FS	Fire Support
FSE	Fire Support Element
FSK	Frequency Shift Keying
FSO	Fire Support Officer
FSTD	Fire Support Test Directorate
FUE	First Unit Equipped
FQT	Formal Qualification Test
FY	Fiscal Year
GCSS	Guardrail Common Sensor System
GFE	Government Furnished Equipment
GLTR	Ground Launch Tacit Rainbow
GPS	Global Positioning System
GS	General Support
GS-R	General Support-Reinforcing
GW	Generic Weapon

HQ	Headquarters
IEEE	Institute of Electrical and Electronics Engineers
IEU	Improved Electronics Unit
IEW	Intelligence and Electronics Warfare
IFCS	Improved Fire Control System
ILMS	Improved Launcher Mechanical System
IMIT	Independent MFOM Integration Test
IOC	Initial Operational Capability
IOT&E	Independent Operational Test and Evaluation
IRS	Interface Requirements Specification
ISIT	Independent System Integration Test
JSTARS	Joint Surveillance/Target Attack Radar System
JTACMS	Joint Tactical Missile System
LCSSE	Life Cycle Software Support Environment
LCU	Lightweight Computer Unit
LDS	Launch Drive System
LIU	Launcher Interface Unit
LPA	Launch Pod Assembly
LPU	Limited Production Urgent
LRIP	Low Rate Initial Production
LRU	Line Replaceable Unit
MCCR	Mission Critical Computer Resource
MFOM	M270 Family of Munitions
MICOM	Missile Command
MLRS	Multiple Launch Rocket System
MMI	Man Machine Interface
MOS	Military Occupational Specialty
MP	Main Processor
MS	Meteorological Sensor
MSD	Mass Storage Device
MTOE	Modified Table of Organization and Equipment
NDI	Non Developmental Item
OT	Operational Test
O&S	Operations and Support
PCU	Power Conditioning Unit
PDR	Preliminary Design Review
PEO	Program Executive Office
PLDMD	Platoon Leaders Digital Message Device

PLL	Prescribed Load List
PLU	Program Load Unit
PM	Project (Product) Manager
PMO	Project (Product) Management Office
PNU	Position/Navigation Unit
PSU	Power Switching Unit
R/T	Receiver/Transmitter
SADARM	Sense and Destroy Armor
SAP	Special Access Program
SCSI	Small Computer System Interface
SDP	Software Development Plan
SDR	System Design Review
SEI	Software Engineering Institute
SICPS	Standardized Integrated Command Post System
SIT	System Integration Test
SPAP	Special Applications Program
SRS	Software Requirements Specification
SSA	Supply Support Activity
SSR	Software Specification Review
STD	Software Test Description
STP	Software Test Plan
STR	Software Test Report
TA	Target Acquisition
TACFIRE	Tactical Fire Direction System
TACOM	Tank Automotive Command
TACMS	Tactical Missile System
TBM	Theater Ballistic Missile
TCP-IP	Transmission Control Protocol - Internet Program
TCU	Transportable Computer Unit
TGW	Terminal Guidance Warhead
TIBS	Tactical Information Broadcast System
TMS	Tactical Missile System
TPF	Total Package Fielding
TRADOC	Training and Doctrine Command
TRR	Test Readiness Review
TSM-FSC2S	TRADOC System Manager-Fire Support C2 Systems
TSM-RAMS	TRADOC System Manager-Rockets and Missiles
TSSAM	Tri-Service Standoff Attack Missile
USAFAS	US Army Field Artillery School
VCSA	Vice Chief of Staff, Army

VFMED	Variable Format Message Entry Device
WIU	Weapon Interface Unit

APPENDIX B. FDDM SYSTEM EMPLOYMENT

This appendix is provided as additional background information concerning the operational employment concept for the FDDM. In the first section, each of the FDDM tactical operating levels is described in detail. The second section describes the FDDM capabilities within each of the operating levels.

The FDDM is the C^2 computer for the MLRS FDC and for each MLRS battery FDC and Battery Operations Center (BOC). It is also employed at the Corps FSEs, and at field artillery brigades to augment the organic capability provided by the TACFIRE and the early versions of the AFATDS. In this role, it replaces the remote terminal to TACFIRE, the VFMED, and provides processing not scheduled to be included initially in AFATDS at selected locations. [Ref. 1, p. 3-1]

A. FDDM SYSTEM ENVIRONMENT

The following describes the operational employment environment at the tactical levels under which the FDDM is deployed.

1. Fire Support Element and Brigade Operations

The FDDM augments the processing provided by TACFIRE to remote subscribers at the Corps FSEs and the field artillery brigades. This affords these units the capability to automate the planning and execution of fires for all supported weapons in their area of interest. The FDDM at the BCD echelons will emulate the functions of the VFMED and provide deep fires planning capabilities. [Ref. 1, p. 3-1]

The FDDM allows the Fire Support Officer (FSO) to perform all operations he currently is capable of with the VFMED, including the composition and transmission of messages, access to TACFIRE's database, and receipt of TACFIRE responses. A library of message formats, used by the VFMED, to build fire plans are available in the FDDM. The availability of these message formats will reduce the communications traffic between TACFIRE and the FSO. With the FDDM, the FSE can digitally communicate with subscribers other than TACFIRE. This may include fire units with special missions, sensors, other target acquisition sources, and lateral unit FSEs. [Ref. 1, p. 3-1]

The FDDM provides the FSO the additional capability to introduce, store, and process weapons information which is not available to the TACFIRE system. The FDDM will allow the FSO to perform "what if" computations based on fire unit, munition, target, and current database matching to determine projected firing parameters for planned targets, to project future ammunition and fire unit requirements, and to estimate probabilities of success on targets of opportunity. [Ref. 1, p. 3-1]

2. MLRS Battalion

The FDDM operates as a net control C^2 computer at the battalion and must interface and interoperate with its subordinate battery FDDMs on the battalion fire direction net (FM digital secure) and on the battalion high frequency command/operations net (voice and/or digital secure). [Ref. 1, p. 3-1]

The FDDM also must operate as a node on the nets of higher echelons, specifically the force field artillery fire direction net (digital FM secure) and the force field artillery command and fire direction nets (voice and/or digital secure). In these nets, the FDDM may interface with TACFIRE or AFATDS at the division artillery, corps artillery, or the field artillery brigade, as well as FDDMs at the various FSEs. [Ref. 1, p. 3-2]

The FDDM may also be configured on a mission required basis to have a direct interface to various target acquisition systems. These systems provide target acquisition and target attack information to support the decentralized execution mode of the commanders concept of the operation. [Ref. 1, p. 3-2]

3. MLRS Battery

Within the battery, the FDDM acts as the net control computer and operates on the battery fire direction net (digital FM secure). On this net, the FDDM must interoperate with the FDS computer at each subordinate platoon headquarters, and the FCS on each M270 launcher. [Ref. 1, p. 3-3]

The MLRS battery FDDM must operate on the controlling headquarters fire direction net and the controlling headquarters command/operations net. It also interfaces with either the controlling headquarters FDDM or TACFIRE/AFATDS. [Ref. 1, p. 3-3]

B. FDDM CAPABILITIES

The FDDM system provides two general capabilities: data and applications processing, and communications distribution.

1. Data and Applications Processing

The FDDM provides 32 megabytes of volatile system memory (dynamic random access memory - DRAM) for the DPU of the CDPU and may be optionally configured with larger amounts of memory for active program storage. Its non-volatile storage consists of a removable hard drive (142 megabyte capacity) and a removable cartridge nine track tape backup system (296 megabyte capacity). In addition, the FDS component (the front-end) has its own program space and hard drive (the FDS will be hosted on the ATTCS common chassis). [Ref. 1, p. 3-3]

The FDDM front-end, the FDS, provides the same basic level of processing performance as does the stand-alone FDS used in MLRS platoons. The FDS is capable of processing basic MLRS DPICM and Army TACMS missions without relying on the specialized processing in the DPU common and special applications. It performs tactical and technical fire control for those munitions including effects processing, target segmentation, fire unit selection, and other field artillery rocket and missile processing. In addition, the FDS component acts as the human machine interface module for FDDM processing. It provides the keyboard and video interfaces to the operator and provides and supports operator inputs to the specialized processing performed within the DPU special applications. [Ref. 1, p. 3-3]

The DPU common applications package provides data management and storage for the common tasks to be conducted by the DPU. In addition, it interfaces with the weapon support applications and provides a Special Applications Support Package for the SPAPs. [Ref. 1, p. 3-3]

The Special Applications Support Package is a set of Ada routines which replaces commonly used system calls with calls to functions in a high order language (Ada). This method insulates the SPAPs from the operating system and allows weapons developers to create applications which may be easily recompiled into usable modules on each host machine. In this manner, relative hardware/operating system independence is supported. Common applications interface with the system in this same manner. [Ref. 1, p. 3-2]

A special application, in general, provides a specific service which is unique to a specific weapon, set of weapons, or task, and is not well suited to performance in a generic manner. Some SPAPs are concerned with the management and utilization of Defense Mapping Agency (DMA) Digital Terrain Elevation Data (DTED), others are concerned with support tasks, and others are concerned with the processing for weapons and may require special security considerations. [Ref. 1, p. 3-2]

One of the primary reasons for the existence of the FDDM is to provide the capability to integrate classified and/or special access weapons programs into the fielded system. With a few commands, entry of some weapon descriptor data, and reading the weapon specific files into the DPU, the FDDM can be configured to perform technical processing for a weapon about which it previously "knew" nothing. With the inclusion of a companion set of weapon application files at the launcher, a "special mission" can be planned, disseminated, and executed in a relatively short period of time without the security risks attendant with "hard coding" all MLRS systems to perform that particular mission. [Ref. 1, p. 3-3]

Special applications, particularly weapon SPAPs, may require databases to be present to represent threat, terrain, targets, capabilities, and/or parametric information. The FDDM SPAP processing allows the special handling, storage, safeguarding, and encoding/decoding of information to be performed without operator intervention and with a much reduced probability of loss or compromise. [Ref. 1, p. 3-3]

The FDDM automatically recognizes weapons or targets which must be processed by one or more DPU special applications. Upon receipt of a "DPU" message, the mission is sent through a process which determines each SPAP that is "interested" in the mission (or message). The SPAPs are then invoked in an abbreviated manner to evaluate their capacity to accomplish the mission or to otherwise process the message. For a fire mission, unless a selection is specified by commander's criteria, a list of eligible weapons is submitted to the operator for selection. Upon selection, the SPAP is invoked to execute the mission. [Ref. 1, p. 3-3]

2. Communications Distribution

The CDU of the CDPU performs all internal and external message routing and net control for the FDDM. The CDU is configured with 16 megabytes and may be configured with up to 32 megabytes of program memory if required. The CDU maintains the FDDM subscriber table, the list of nodes which the FDDM can "talk to", the net or port to which the subscriber belongs, and the type of subscriber. [Ref. 1, p. 3-3]

The CDU routes incoming messages to the operator via the FDS component and to the DPU. It queues message for transmission and monitors the networks according to subscriber parameters set during system setup. Each net has its own parametric setup. The FDDM is capable of receiving or transmitting communications to any of four ports. The FDDM also controls two five-wire and two three-wire RS-232 ports. The two five-wire ports are used for input/output for the Program Load Unit (PLU) while the two three-wire ports are available for use under the DPU (SPAP) control.

The PLU capability allows the configuration of program loads for the FCS on the launcher and permits the reading or writing of tactical message to bubble memory cassette. Operational programs and files for the CPU and CDU may be read from or written to the PLU cassette. [Ref. 1, p. 3-3]

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